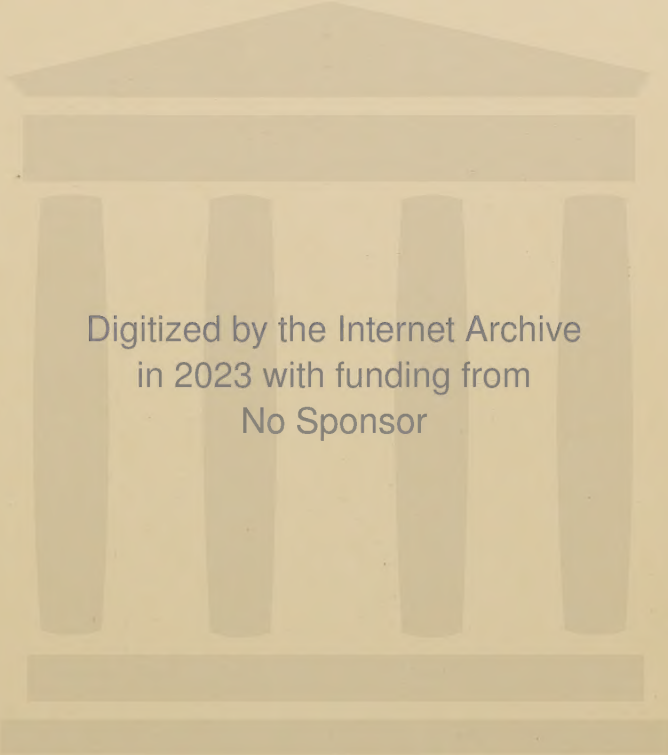




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ELEMENTARY FOUNDRY TECHNOLOGY

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ELEMENTARY FOUNDRY TECHNOLOGY

WITH SPECIAL REFERENCE TO
GRAY IRON AND STEEL

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PREFACE

This text on Elementary Foundry Technology with special reference to gray iron and steel is one of a series of texts which is being prepared to serve the foundry in schools and in industry. These texts conform to the requirements for instructional material as set up in the Minimum Standards of Four-year Foundry Apprenticeship in the United States of America. A copy of these Standards may be obtained from the National Founders Association or from the American Foundrymen's Association, both of Chicago, or from any District Foundrymen's Association.

THE EDITOR,

CHICAGO, ILL.
October, 1928.

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ACKNOWLEDGMENTS

Without the cooperation of many foundry leaders, this text would have been impossible. And if there had not been available a body of technical subject matter in reference books and in papers published in the Transactions of the American Foundrymen's Association, such a textbook as this would have required years of research and investigation. As a result of having the assistance of these experts in the preparation of certain sections, and of having this wealth of reference material at hand, it has been possible to make of this text an elementary source book, for foundry students, with special reference to gray iron and steel.

The preparation of lessons in Elementary Foundry Technology was originally suggested as a special project of the Apprentice Committee of the Pittsburgh Foundrymen's Association. The following persons served on this original committee: Chairman, C. D. Carey, American Steel Foundries; A. J. Hartman, United Engineering and Foundry Company; D. J. Evans, Union Steel Casting Company; Ralph W. Jones, Union Switch and Signal Company; L. W. Mesta, Mesta Machine Company; L. V. Stevens, Locomotive Stoker Company; W. E. Trautman, Duquesne Steel Foundry Company; E. S. McClelland, Westinghouse Electric and Manufacturing Company; James Jones, Pittsburgh Valve Foundry and Construction Company; William K. Frank, Damascus Bronze Company; H. T. Irwin, Rosedale Foundry and Machine Company; C. B. Connelley, Carnegie Institute of Technology; Frank M. Leavitt, Associate Superintendent, Pittsburgh Public Schools; R. A. Peebles, Mesta Machine Company; Henry Spilker, Sterrit-Thomas Company; R. P. Kennedy, Secretary-Manager, Employers' Association; E. F. Harris, Mesta Machine Company; C. S. Coler, Westinghouse Electric and Manufacturing Company.

The upper and lower limits of the instruction and the general nature of the subject matter were decided by this committee. The committee chose Mr. R. A. Peebles of the Mesta Machine Company as its special representative to assist in the preparation of the text material. Mr. Peebles, cooperating with the several Pittsburgh contacts and with the editor, prepared the original draft of the manuscript for the earlier chapters.

Coordination of material from different fields was required. The result of this coordination had to be well balanced and unified if it was to be useful to public vocational schools as well as to foundrymen. It was necessary to select, from elementary physics and chemistry, subject matter broad enough in scope to furnish a foundation for the contributions of the technical experts who prepared parts of the text. This material had to be in accordance with recent scientific theory, naturally, and yet it had to be stated simply and clearly. Then it had to be organized from the standpoint of modern teaching practice which includes adaptation to the range of individual differences to be expected among students. Finally, and most important, there was needed a careful tying in of foundry operations and processes with each scientific fact presented.

The editor was fortunate in securing the services of Miss Alice M. Loomis whose training in science, experience in college teaching, supervision of vocational education activities, and recent graduate study have been supplemented by service directly in industry. She rendered valuable assistance not only in coordinating the contributions of others but, also, in cooperation with practical foundrymen in the preparation of some parts of the manuscript.

Mr. W. C. Wright, a practical foundryman of many years' experience, contributed valuable suggestions in the course of the revision and reorganization of manuscript.

Mr. A. A. Grubb, Director of Laboratories, The Ohio Brass Company, prepared the manuscript dealing with Foundry Sands and assisted through constructive comment on related subjects.

Maj. R. A. Bull, Director, Electric Steel Founders' Research Group, prepared the section on Electric Steel Production and made helpful suggestions concerning other subject matter.

Prof. A. C. Jewett, Director, College of Industries, and Prof. William H. Dosey, Head Instructor in Foundry, assisted by Prof. Robert B. Leighou, Head of Department of Industrial Science, and Prof. Charles C. Leeds, Head of Department of Works Management, Carnegie Institute of Technology, reviewed all of the material in the first nine parts of the book. The text was improved as a result of their many valuable suggestions.

Mr. E. H. Ballard, General Foundry and Pattern Shop Superintendent, General Electric Company, West Lynn, Mass., assisted by Mr. Roger D. Carver, Metallurgist of this company, contributed materially by their careful review of cupola practice and related topics. Mr. H. V. Crawford, Industrial Department of the General Electric Company, Schenectady, N. Y., cooperated in furnishing recent data regarding cupola practice.

The section on Molding Machines was developed from material originally prepared under the direction of a Committee on Foundry Methods, and elaborated with the assistance of W. C. Wright. It was later modified to conform to suggestions of Mr. H. B. Swan, Superintendent of Foundries, Cadillac Motor Car Company, Detroit, Mich., and supplemented by material prepared by Mr. Clarence S. Wright and other foundrymen. Mr. Clarence S. Wright also gave valuable assistance in developing subject matter on cupola practice and materials.

Mr. R. E. Kennedy, Technical Secretary, American Foundrymen's Association, rendered valuable service through painstaking review of the manuscript, followed by constructive suggestions for improvement of the subject matter and choice of references. His experience as foundry instructor and editor of the Transactions of the American Foundrymen's Association is reflected in the material.

Dr. F. G. Bonser, Professor of Education, Teachers College, Columbia University, reviewed the text for pedagogical arrangement and instructional value of questions and prob-

lems. Revisions were made to conform to his several suggestions.

Dr. Richard Moldenke, because of his long practical and scientific experience in operating foundries and serving as consultant, was selected for the final review of those parts of the text which concern the principles of iron founding and certain debatable points upon which agreement seemed difficult.

The list of references included in this book, and the page references to them following each chapter, indicate the main sources to which this text is indebted for material.

Special acknowledgment is due Mr. L. W. Olson, Works Manager, The Ohio Brass Company, Mansfield, Ohio, whose counsel and cooperation are evident throughout the book. The members of the Committee on Industrial Education, of which he is Chairman, consisting of C. S. Koch, Fort Pitt Steel Casting Company, McKeesport, Pa.; George K. Wilson, Deere and Company, Moline, Ill.; Clarence R. Falk, The Falk Corporation, Milwaukee, Wis.; Dr. Harry Myers, Delco-Light Company, Dayton, Ohio; and E. H. Ballard, General Electric Company, West Lynn, Mass., have furnished constructive direction in the enterprise.

Acknowledgment is gratefully made, also, to those many individuals whose names do not appear above but who gave generously from their experience in foundry, clerical, and educational fields, the varied kinds of assistance that are necessary to make a book, such as this, serviceable to its prospective readers.

THE EDITOR.

CHICAGO, ILL.
October, 1928.

FOREWORD

The fascinating history of the development of the iron industry begins with the struggle of individuals emerging from the Stone Age into the age when iron was first used for implements of warfare and domesticity. It can be traced through the periods of family industries and of the first small workshops. As the family industries were the basis of national and international industrial organizations, so the early workshops laid the foundation for our modern factory system.

The guilds of the Middle Ages exercised autocratic power in regulating the social and industrial activities of communities. The employer as master workman controlled not only the production and distribution of the necessities of life but influenced also to a great extent the artistic development of the time.

The autobiography of Benvenuto Cellini tells of his struggles in casting his bronze Perseus in spite of the handicap of crude materials and equipment and the lack of fundamental knowledge of scientific principles. Many years later, these same struggles and consequent disappointments were experienced by Seth Boyden and urged him on his epochal research which resulted in the production of malleable iron. These pioneers had to overcome the reactionary effect of the practice, common in former ages, of confining valuable industrial information to a limited number of master workmen.

Much of modern industrial progress is a direct result of our making generally available the growing body of information upon which advancement depends. Universities and research organizations have shared with individual scientists the responsibility for discovering and making generally available needed information. Nowhere has this service been more noticeable than in the foundry industry.

The time has come when the available information regarding foundry processes is much greater in amount than can be

carried to the place of application by the present channels for distribution. Scientific achievements are increasingly interwoven with our lives. It is essential that those who perform and supervise fundamental operations should possess sufficient information to co-operate intelligently with engineers and research experts. This is especially true of foundry work.

The text of this book is happily simple and plain. The young student with only a little knowledge of chemistry should be able to understand the book in the light of foundry experiences. Foremen whose opportunities for instruction in foundry science have been less than they would wish will find the book helpful. Even the laboratory assistant will find food for thought in the many applications. It is one thing to make an analysis and quite another to interpret it correctly for direct application to foundry procedure.

Really valuable books for the students of foundry practice are few and this book is welcomed. It is up-to-date and dependable and is just what the beginner needs to set him on the path of his life work with a correct start. He need not later "unlearn" anything. The book is certain to be of great service to the industry in the training of the rising generation of foundrymen.

DR. RICHARD MOLDENKE.

WATCHUNG, NEW JERSEY.
October, 1928.

CONTENTS

PREFACE	PAGE v
ACKNOWLEDGMENTS	vii
FOREWORD	xi
INTRODUCTION	xvii

PART I

SUBSTANCES AND THEIR STRUCTURE

CHAPTER	
I. Changes in Matter.	3
II. Structure of Matter	9
III. Combinations of Elements	13
IV. Chemical Attractions	18
V. Cohesion and Adhesion.	23
VI. Contraction, Shrinkage, and Expansion.	28
VII. Acids, Bases, and Salts.	38

PART II

SOME PHYSICAL PROPERTIES

VIII. Measurements	49
IX. Weight, Density, and Specific Gravity.	53
X. Inertia.	59
XI. Elasticity.	61
XII. Friction	64
XIII. Friction and Efficiency.	67
XIV. Melting Points of Metals.	70
XV. Fluidity and Life of Molten Metals	75
XVI. Humidity.	80

PART III

OXIDATION, REDUCTION, AND COMBUSTION

XVII. Oxidation.	85
XVIII. Oxidation and Reduction of Metals	91
XIX. Combustion.	95
XX. Effects of Products of Combustion upon Animal Life	104

PART IV

FORCE AND MOTION

CHAPTER	PAGE
XXI. Force	111
XXII. Work	115
XXIII. Energy.	118
XXIV. Power	123
XXV. Motion.	125
XXVI. Gravity as a Force.	128
XXVII. Heat.	130
XXVIII. Light	137
XXIX. Electricity and Magnetism	140

PART V

APPLICATION OF FORCE

XXX. Simple Levers and Lever Systems	149
XXXI. Tackle, Blocks, and Pulleys.	154
XXXII. Gears	158
XXXIII. Inclined Plane, Wedge, and Screw.	162

PART VI

MECHANICS OF FLUIDS

XXXIV. Transmission of Pressure by Fluids	167
XXXV. The Hydraulic Press.	170
XXXVI. Pneumatic Tools and Equipment	173
XXXVII. Steam	175

PART VII

EFFECTS OF ELEMENTS ON IRON

XXXVIII. Carbon and Its Effect on Iron.	179
XXXIX. Silicon and Its Effect on Iron	185
XL. Manganese and Its Effect on Iron	192
XLI. Phosphorus and Its Effect on Iron.	197
XLII. Sulphur and Its Effect on Iron	202

PART VIII

IRON

XLIII. Occurrence.	209
XLIV. Transportation of Ores to Furnaces	212
XLV. Description of Blast Furnace	214
XLVI. Operation of Blast Furnace—Smelting Practice.	218

CONTENTS

xv

CHAPTER	PAGE
XLVII. Classification of Pig Iron.	222
XLVIII. Scrap	226

PART IX

THE CUPOLA

XLIX. Description of the Cupola	235
L. Operation of the Cupola	247
LI. Calculating Mixtures—Section I. Calculating Mix- tures—Section II	254
LII. Charging the Cupola.	265

PART X

FOUNDRY SANDS—A. A. GRUBB, DIRECTOR OF LABORATORIES, THE OHIO BRASS COMPANY

LIII. Composition and Particle Size.	271
LIV. Molding Properties	276
LV. Molding Properties—Permeability and Temper.	281
LVI. Sand Control.	284
LVII. Brass Foundry Sands	287
LVIII. Iron Foundry Sands.	290
LIX. Steel Foundry Sands.	293
LX. Core Sands.	297
LXI. Core Sands (<i>Continued</i>)	300

PART XI

ELEMENTARY PROBLEMS IN ELECTRIC STEEL FOUNDRY PRODUCTION— MAJOR R. A. BULL, DIRECTOR, ELECTRIC STEEL FOUNDERS' RESEARCH GROUP

LXII. The Proper Field of the Electric Furnace in Steel Casting Manufacture	307
LXIII. Problems Related to High Temperature of Metal and to Sand.	311
LXIV. Melting, Pouring, and General Equipment	317
LXV. Equipment (<i>Continued</i>).	323

PART XII

MOLDING MACHINES

LXVI. Mechanical Production in Industry	331
LXVII. Hand Squeezers and Squeezer Pattern Equipment— Introduction to the Study of Power Squeezers	338
LXVIII. Power Squeezers.	350

CHAPTER	PAGE
LXIX. Stripping Plate Machines and Rigging.	363
LXX. Roll-over, Jar, Ramming, and Pattern Drawing Machines.	372
LXXI. Long-life Molds.	380
LXXII. Sandslinger Molding Machines	385
LXXIII. Miscellaneous Molding and Core-room Equipment . .	393
GLOSSARY.	400
BIBLIOGRAPHY.	406
INDEX	409

INTRODUCTION

The aim of this text is to suggest applications of elementary science to foundry operations, furnish students with references to generally accepted sources of information, and to stimulate interest of students in further study and research.

Recent developments in the foundry industry have demonstrated an unmistakable trend toward scientific control of operations and processes. The 20-year period during which labor-saving equipment was developed beyond the expectations of most foundrymen of the last generation has been succeeded by a period wherein scientific research is certain to parallel mechanical progress.

Scientific research is already far ahead of application. Because the dissemination of technical information has been neglected and the means for presenting new ideas have been inadequate, application of auxiliary information has lagged far behind the achievements of research engineers and foundry experts.

As a result of the work of the American Foundrymen's Association, whose principal aim is to stimulate research and distribute information, this body of scientific and operating information is constantly and rapidly growing. At the same time, the number of skilled foundrymen possessing understanding of recent developments has been steadily diminishing.

A group of foundrymen who have sufficient foundation to understand what engineers and technical experts are talking and writing about, must be trained to introduce technical ideas.

This group should not only understand the practices in local plants, but, also, should understand something of the newer methods being introduced throughout the industry. These men need the first-hand knowledge of operations which can be gained only by several years of foundry work. The nature of this work, like certain types of engineering, will

eliminate those young men who are in search of easy positions. The reward of those who gain this experience is certain.

Apprentice training and vocational education with foundry practice offer the best opportunity for the development of such a group. To be of practical value in modern foundries, this training must be divided into two parts: (1) practical experience in foundry work; (2) instruction and supervised training in applying scientific and trade information to foundry operations.

In order to furnish instructional material needed in schools training students for the foundry, this text is planned to meet the requirements of the "Minimum Standards of Four-year Foundry Apprenticeship in the United States of America." These standards are generally accepted in the industry where training is carried on, and they have been officially adopted by leading foundry associations. Also, these standards conform to the requirements of Federal and State Vocational Acts.

Science for foundry apprentices differs fundamentally from the science commonly taught to workers in most of the metal trades. General science suited to the other metal trades is of limited practical value to foundry apprentices. For example, machinist apprentices are chiefly concerned with physical changes. This is true, also, of apprentices in many other metal trades.

The elementary physical principles used in foundry work include not only those in mechanics but also those involving the complex effects of heat upon metals. Foundry apprentices are as much if not more concerned with chemistry than with physics. Furthermore, the chemistry and physics of metals offer one of the most interesting and productive fields of opportunity, because the use of metals is being rapidly extended into fields wherein metals have been previously less appreciated.

Foundry science is basic as is the industry, and an understanding of the physics and chemistry in foundry operations is of direct value in all metal trades. This fact has been generally recognized and has led to the present practice of most engineer-

ing schools, technical high schools, trade schools, and vocational schools including foundry courses as fundamental.

In the past, these foundry courses in schools preparing students for various professions and trades have depended upon instructors for outlines. The effectiveness of the instruction has, in turn, depended to a great extent upon the teacher's experience and his acquaintance with available sources of information.

Foundry shop instructors are usually chosen because of their practical experience and in many cases are not familiar with scientific progress. Since the shop instructors usually cannot teach foundry science, it is taught by science instructors. These men, while being well grounded in science, frequently do not possess ability to apply their special knowledge nor do they know where to obtain reliable reference books. Numerous requests from these teachers for text material and outlines have been one reason for the preparation of this book.

This book is not intended as a reference on foundry technology. While an earnest effort has been made to assure the accuracy of scientific statements and to include many applications from recent foundry experiences, the primary purpose has been to stimulate reasoning and awaken a desire upon the part of students to search, in their experience and in the references, for more complete information. With this in view, page references are given to a number of publications. Instructors and practical students studying certain operating problems will appreciate this saving of their time.

References have been chosen with three ends in view: (1) their general acceptance by progressive foundrymen; (2) their availability to foundry students; (3) their general acceptance by science teachers in the basic metal trades. The number of references has been reduced as far as possible out of regard for the limited opportunities of some students and schools in the purchase of reference books.

Students who study these lessons should have the few references, in the first list, available at all times. In order to assist instructors and students who desire to read beyond these sources, additional references are given in a second list.

Except where the reference material is brief and wholly pertinent to the subject, the references in both lists have been to certain pages.

A test of text material in science related to a trade or industrial pursuit is: "Will the study and application of principles set forth in the text render the doing of the work easier, cheaper, or more interesting?" This test of instruction is set forth in the "Minimum Standards of Four-year Foundry Apprenticeship in the United States of America."

In order to test the material in this book by the standard for related science instruction, it was used in a correspondence course in a typical foundry. As a result of this experience, many practical questions were found and, also, a number of additions and restatements needed in the text material. Revisions and additions were then made in order to insure better understanding.

A great majority of the 600 questions and problems following the chapters have been taken from foundry situations in which difficulties have been overcome by the use of the principles of science presented in the preceding material. A large number have been asked by those who sought information as to the "why and wherefore" of their work in the foundry. Other questions have been included in order to help students further in the prevention of difficulties and in stimulating them to reason regarding foundry operations. All these questions and problems require reasoning in which both the instructional material and foundry experience must be used. Care has been used to avoid all questions which could be answered by guessing or by memorization of the text. In other words, experience in foundry work is essential to an understanding of science as it is here presented, and an endeavor has been made so to present the science that students will be stimulated to reason.

All of the illustrations of scientific subject matter are taken from the foundry. For example, in Chap. VII, the theory of acids, bases, and salts is presented as it would be in any book on elementary science; but in this case the acids discussed include sulphuric and hydrofluoric, which are used in cleaning castings, and silica, the "acid of metallurgists." Neutraliza-

tion includes consideration of the selection of cupola linings adapted to acid and basic charges.

Every detail of the subject matter, every question, and every problem is definitely and specifically tied in with foundry work.

No attempt has been made to prepare either a complete text on general science or a general reference book on Foundry Technology; rather it is intended to furnish subject matter upon which may be based a comprehensive course in elementary Foundry Technology.

The range of previous schooling of the students who will use this text had to be considered. This range is greater than may be expected by the average teacher or foundryman. In some favored localities, foundries employ largely high-school graduates who have had excellent instruction in science. These students will need only a brief review if any consideration of some parts of this book. Other parts of the text, however, will interest the more advanced students. Foundrymen and instructors in these communities may be reminded of the great number of places in which apprentices are employed who, if they possess the equivalent of an eighth grade education have left school before finishing the eighth grade. It has been observed that in many plants, the range of previous schooling of apprentices is considerable.

This wide spread in the previous schooling of foundry apprentices produces a similar variation in suitable instructional material.

The range of subject matter has made necessary the inclusion of more material than can be presented effectively during the usual time allotted to science subjects in part-time vocational courses, or other courses including foundry instruction. Instructors of students of all degrees of advancement will be able to select topics and make assignments according to individual instructional needs.

The limitation of space in one book prevents even the most elementary treatment of the problems in the different kinds of ferrous and non-ferrous foundries. Since gray iron castings are the most numerous and since many of the principles in the founding of gray iron are applicable in white

iron, malleable, and steel foundries, most of the applications are to the gray iron foundry. The first parts of the book dealing with elementary science and the sections on Foundry Sands and Molding Machines are applicable to all kinds of foundries.

As sections were prepared, they were submitted first to technical experts, next to operating foundrymen, then again to the technical men. Soon it was evident that agreement, between foundrymen, on certain points was difficult to obtain. This led to the practice of teaching debatable sections under plant conditions with opportunity for observation of results.

During the two years the material in this book was in the process of development, many visits were made to different parts of the country in order to evaluate the difficult lessons in the light of local conditions. Foundry apprentices and foremen whose experience had not included instruction in related science were among these students. Foundrymen and school officials cooperated freely in helping to adapt text material to local needs.

Throughout this experimental use of the text material, the test of related instruction set forth in the "Minimum Standards of Four-year Foundry Apprenticeship" was kept in mind. Material which did not make it easier, cheaper, or more interesting to do foundry work was either discarded as unrelated or its relationship established.

The result of this testing and revising of the contributions of many authors has been the strengthening of the text. The experiences in industry, and in schools, and colleges during this method of preparing the publication have produced many evidences of the special need for and interest in this type of instructional material.

PART I
SUBSTANCES AND THEIR STRUCTURE

ELEMENTARY FOUNDRY TECHNOLOGY

CHAPTER I

CHANGES IN MATTER

The foundry is a great chemical and physical laboratory in the service of modern civilization. Every advance in transportation from ox carts to airplanes, every improved method of sending and receiving messages, the appliances that cool and heat and support our increasingly larger buildings, in fact, all the changes and articles in our modern life that involve the use of castings in production or operation are dependent upon the foundry. The foundryman not only uses the results of research work in many fields, but is himself, by constant study of his own technical problems, adding to the sum total of knowledge in the service of industry.

There is no definite boundry line between physics and chemistry. In general, chemistry deals with matter, with the materials and substances of which matter is made up, and with changes in their nature. Physics deals with matter without regard to its composition but with regard to the effects of force, motion, and energy in various forms. The changes in the melting and pouring of metal, which the foundryman desires to control, make chemistry a subject of special interest to him.

A foundryman today does not need to be a chemist. Chemist service is available in most large plants, in the small plants which are parts of a large corporation, and from leading firms supplying materials to the small plants.

A foundryman does need, however, to use a little chemistry in buying his pig iron and other raw materials, in the mixing

of metals, in the calculation of charges, and in the operation of the cupola. A certain amount of expensive alloy may be the cheapest way of obtaining a particular quality of casting, and any more of the alloy may have a bad effect. Certain defects in castings can be prevented by a knowledge of the chemical principles involved in the process.

Materials are the form in which matter is usually thought of in daily life. Material is a very general term. Pig iron is a raw material in the iron foundry. Core oil and sand are materials. In order to turn out a product of a definite standard, it is necessary to examine into the nature of materials. A material may be excellent, unsatisfactory, or have any intermediate quality depending upon the qualities and proportions of the substances of which it is composed.

A substance is a particular kind of matter having certain definite characteristics or qualities. Cloth is a material which may contain one or more substances. It may be made of wool and cotton (two substances) or of all wool, or all silk, or of other combinations of substances. Commercial iron, coke, sulphur, sand, and clay are composed of mixtures of substances. A machine, the finished material, may contain iron, wood, paint, and other substances.

In the past, it was stated that the simplest most fundamental law of chemistry is that every material consists of substances each of which has a definite set of specific properties or characteristics. More recent knowledge of matter and energy has proved that substances as we know them, even the elements, can be broken down into others with different characteristics. But for all practical purposes, at present, we may say that in order to use materials so as to get desired results, the characteristics of the substances composing them must be studied. The melting and setting points and the fluidity of molten metal, the hardness of the finished castings, the temper of the sand, can all be traced back to definite properties of the substances of which they are composed.

Physical States of Matter.—Matter may change its state and form new products with quite different qualities. A number of substances are known in solid, liquid, and gaseous forms. These are called physical states of matter, because the changes

from one to the other are physical rather than chemical in nature. The distinction between physical and chemical changes will be made clear later.

The foundryman is concerned with metals in the liquid state as well as in the solid, and sometimes even in the gaseous state. The characteristics which appear during these changes furnish many of the problems in this industry. Why, for instance, should cold shuts appear on the surface of castings indicating that the change from the liquid to the solid state has not taken place satisfactorily? Such questions as these can be answered only by a careful consideration of the conditions affecting the changes of metal from the molten to the solid form.

Solids tend to preserve definite size and shape; liquids tend to preserve definite size only, while their shape conforms to that of the containing vessel; gases tend to preserve neither definite size nor shape but to expand indefinitely. This characteristic of gases accounts for their penetrating quality. The term "fluid" includes both liquids and gases since they both tend to flow.

Chemical and Physical Changes.—During the setting of iron, both physical and chemical changes are taking place. The exact changes are so sensitive to conditions that a draft of cold air, the use of wetter sand than usual, or any one of many other situations may greatly alter the quality of the product. Some of these conditions are well understood by all good workers with some knowledge of foundry science, others require the services of experts, and still others are the subjects of serious study.

Changes which take place in substances may be either *chemical* or *physical*. A chemical change results in the production of new substances. A physical change does not produce new substances but only changes in various characteristics of the original substance. These general distinctions are sometimes helpful.

When water is changed to ice or steam, only a physical change takes place. The substance of ice is the same as that of water. Although steam occupies over fifteen hundred times the space of the water from which it is produced, it is still the

same substance as water, and is readily condensed into its former form.

An entirely different change takes place in water when it is decomposed by means of a direct electric current. This can be done by passing a direct current through two tubes filled with water. A little sulphuric acid is added to the water so that it will conduct the electric current more readily. The apparatus is so arranged that the gases escaping in the negative and positive tubes are separate. As the current is passed, twice as much gas forms in the negative tube as in the positive. This larger volume of gas is hydrogen and burns with intense heat. The smaller volume of gas is oxygen.

A chemical change has been produced by the electrolysis of water with the production of hydrogen and oxygen, two substances entirely different from water. When these two substances unite to form water, a chemical change occurs. The moisture which is sometimes seen near the place where an oxy-acetylene torch is being used is probably the result of the union of hydrogen with oxygen.

A number of chemical and physical changes are usually desired in the production of castings and a few others are carefully avoided.

An understanding of chemical and physical changes makes the law of the conservation of matter seem very simple. This was not the case 150 years ago when Lavoisier was performing experiments which led him to conclude that changes in form do not destroy or produce matter. The law of conservation stated that matter is neither destroyed nor created however much the form may be changed. This law was accepted as absolute for over a century. Today, it is known that matter and energy are not so distinct as was formerly thought. There is evidence that matter in some cases appears as energy and that the reverse change may occur. This modifies and extends the old law of conservation to include energy as well as matter, but it does not discredit the essential principle. In industry, at present, one may safely seek for the various forms into which matter is converted.

When coke is burned, the carbon, the small amounts of sulphur, ash, moisture, and other constituents could all be

found, weighed, and exactly accounted for if the combustion were done under carefully controlled conditions. In fact, the products of combustion always weigh more than the materials burned because of the added weight of oxygen from the air which enters into combination with some of the substances burned.

Topical Questions

1. Why may foreign scrap give trouble in a foundry?
2. Explain the distinction between liquids and fluids. Illustrate.
3. Which is more readily detected by its odor, a solid, a liquid, or a gas? Explain why.
4. Classify the following changes as to chemical or physical:
 - (a) Burning of fuel.
 - (b) Chipping-out.
 - (c) Action of flux.
 - (d) Formation of a scab in molding.
 - (e) Formation of shot in pouring.
 - (f) Melting of ice.
5. What kinds of change (physical, chemical, or both) occur in each of the following:
 - (a) The tempering of sand?
 - (b) The slaking of lime?
 - (c) The firing of a rifle?
 - (d) The melting off of the end of a test iron bar?
 - (e) Cupola melting process?
 - (f) Slow setting of iron?
 - (g) Skimming?
 - (h) The effect upon cement of water freezing in crevices?
 - (i) Annealing?
6. Give three other examples from the foundry of:
 - (a) Physical change.
 - (b) Chemical change.
7. Give an example of cleaning in the foundry or elsewhere in which:
 - (a) A chemical change takes place.
 - (b) Only a physical change takes place.
8. Give an example from the foundry for each of the four forms of change stated below and mention a specific name for this particular change. ("Freezing" is a specific name for the change of water from liquid to solid form.)
 - (a) From solid to liquid.
 - (b) From liquid to gas.
 - (c) From liquid to solid.
 - (d) From gas to liquid.

9. (a) State the law of the conservation of matter.
- (b) Explain the application of this law in the burning of coal or coke in the cupola, mentioning four places where certain parts of the fuel go.

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1. BRADBURY, ROBERT H., "A First Book in Chemistry," Chap. I; pp. 27-28.
2. HIGGINS, LOTHROP D., "Introductory Physics," p. 5, pars. 4-5; pp. 9-10, pars. 9-10.
3. SEARS, FREDERICK E., "Physics for Secondary Schools," pp. 335-336, pars. 276-277.

Reading References

1. SMITH's "Intermediate Chemistry," revised and rewritten, JAMES KENDALL and EDWIN E. SLOSSON, pp. iii to viii, "Why Study Chemistry;" Chaps. I, II; pp. 64-65, "The States of Matter."
2. SLOSSON, E. E., "Chats on Chemistry," "Do Two and Two Make Four?" Chap. XX.

CHAPTER II

STRUCTURE OF MATTER

For thousands of years, a few investigators have been seeking to find out what familiar substances are really made of, how matter is constructed, and how to change one kind of material into another. The alchemists of the middle ages were especially concerned with the changing of the so-called base metals into gold—the transmutation of metals this was called. The discovery of phosphorus as a separate substance was one of the unexpected results of this search.

Elements.—As substances were analyzed in chemical laboratories, it became apparent that there was a limit beyond which this breaking down process did not go. All the materials worked with were broken down into a comparatively few substances which were called elements. The limited number of elements, however, does not indicate a meagre possibility as to the number and variety of substances that can be made from them. The 26 letters in the alphabet do not indicate a limited number of words in a language.

At present, about 80 elements are known, several new ones having been discovered recently. Of these 80, only about 16 occur abundantly on the earth's surface or are known to be of special importance to mankind. About three-fourths of the known elements are classed as metals and the others as non-metals.

Oxygen, silicon, aluminum, iron, and calcium, in this order, are the most abundant elements on the part of the earth's surface about which anything is known. Titanium, the tenth most abundant element, and carbon, the eleventh or twelfth element in abundance, are also of interest in the foundry.

Until recently, an element was frequently defined as a substance which had not been broken down into more simple materials of a different nature. Thus, carbon was called an

element because it had not been broken down into different substances. Sugar was considered not to be an element because it contained carbon as well as other elements, could easily be charred so as to show the carbon formed by this partial burning, or it could be burned completely so as to produce several entirely new substances.

The recent discoveries regarding radioactivity, and the observations on the disintegration of radioactive substances, have proved that the materials formerly recognized as elements can be broken up or disintegrated with the production of other elements. For example, thorium, a rare element, in its disintegration produces helium, radium, and, finally, lead.

The transmutation of elements, long believed to be an impossibility, is now accepted as an indisputable fact, although at present it is largely beyond the control of mankind.

The discoveries regarding the possibility of separating all elements into a few simpler units do not disprove the previous conception of the structure of matter. They may modify or extend the ideas on this subject, and in some cases they confirm the earlier theories.

An *element* is now defined as one of the simpler forms of matter, either free or in combination. The term is applied as before to iron, copper, carbon, and other simple forms of matter.

The molecular theory is now accepted as a fact. A *molecule* is the smallest particle of any substance which has the properties of the original substance. The molecules of a substance are like each other, but different from the molecules of all other substances. These differences may be great or small, but they are always reflected in the characteristics of the substances themselves. For example, glass containing much lead is always heavier than glass the molecules in which contain less lead.

A molecule of water, as was explained in the discussion of chemical changes, is composed of two parts of hydrogen and one of oxygen. These particles are called atoms. An *atom* is the smallest subdivision of an element. Atoms are the elementary parts of a molecule; and a molecule may contain one or more atoms. These atoms may be of the same or of

different elements. The molecule of common table salt is composed of one atom of sodium and one atom of chlorine.

A molecule of iron contains one atom (of iron of course) but a molecule of oxygen contains two atoms of oxygen. The fact that atoms of oxygen tend to unite with each other rather than remain out of combination suggests an important characteristic of oxygen: oxygen is a very active element chemically. In fact, atoms of oxygen exist out of combination only briefly and this is when a difference in chemical attraction causes a change in chemical combination. Relative chemical affinities or attractions play a large part in the operation of a cupola and will be considered in detail under the various elements.

As more has been learned about elements, atoms, molecules, and their arrangement in the structure of matter, it has been possible to make new substances. Chemical dictionaries list about 300,000 substances the larger part of which have been made by man and are not found in nature. For example, coal tar, a by-product of the process in which coke is produced, is the source of hundreds of substances including explosives, brilliant dyes, poison gases, perfumes, and medicines.

Chemical Symbols.—Since elements and molecules play such a large part in important chemical processes, it is natural that abbreviations or symbols should be used in reference to them. Chemical symbols are used just as lb. or # and T. are used as symbols of pounds and tons. The first letter of the name of an element is usually used as its *chemical symbol* unless this would cause confusion. C is the symbol for carbon, H for hydrogen, and S for sulphur. When it is necessary to prevent confusion, the first two letters or two characteristic letters may be used as Ca for calcium, Si for silicon, and Mn for manganese.

Scientists throughout the world have agreed to use the same symbols for the elements. This is simple when the words are similar but not when quite different words are used. In these cases, the chemical symbols are taken from the Latin names of the elements. This is really helpful for frequently the Latin root is found in many common English words. The chemical symbol of iron is Fe from the Latin *ferrum*

meaning iron. Such words as ferromanganese, a combination of iron and manganese, and non-ferrous, referring to other metals than iron, are derived from the same root as the chemical symbol of iron.

Topical Questions

1. Name three common substances that are elements. Explain what this means. (These substances may contain negligible quantities of other materials.)

2. What is the main element in each of following? Give both name and chemical symbol.

(a) Lead in lead pencils.

(b) Lead pipes.

(c) Black lead.

(d) Lead which causes lead poisoning.

(e) Plumbago.

(f) Facing (foundry).

3. Write the chemical symbols in answering each of these questions.

(a) Which of the 15 elements Bradbury calls the most important in plant and animal life, are among the 12 most abundant elements? (b) Which 7 of the elements most important to living bodies are also of great concern in ferrous foundries? (c) What elements are of particular interest in the brass foundry in addition to those in the two lists previously referred to? To find composition of brass, use index of any reference book or a large dictionary.

4. Name four common materials the partial burning of which shows that they contain the element carbon.

5. What derivatives of coal tar are used in the foundry or elsewhere in your experience?

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1. BRADBURY, ROBERT H., "A First Book in Chemistry," Chap. VI; pp. 19-24, 219, 661-662.

2. HIGGINS, LOTHROP H., "Introductory Physics," p. 11, par. 12.

3. SEARS, FREDERICK E., "Physics for Secondary Schools," pp. 101, 110, 645-646.

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1. SMITH'S, "Intermediate Chemistry," revised and rewritten, JAMES KENDALL and EDWIN E. SLOSSON, pp. 544-548.

2. SLOSSON, EDWIN E., "Chats on Science," pp. 66-71, 259-263.

CHAPTER III

COMBINATIONS OF ELEMENTS

Only a few of the familiar substances are elements in the chemical sense. Cast iron, brass, wool, silk, wood, coal, and the great majority of the thousands of materials dealt with daily, are each composed of a number of elements.

Frequently, the names of elements are given to substances found in daily life; but, in reality, these elements in their pure or unmixed state rarely are seen. Pure iron is silver gray and quite soft, and pure gold is too soft to serve any practical purpose. Aluminum, the most abundant metallic element, never occurs as such in nature. It forms a considerable portion of clay and is separated from combination only by means of intense heat, such as is produced in the electric furnace.

In order to produce or use materials intelligently, one sometimes needs to know not only of what elements each material is composed, but also how these elements are combined, what qualities each gives to the material, and how they affect each other. This is particularly true in the foundry where it is desired to produce castings having specific qualities.

A very small amount of titanium added to the cupola may increase the strength of iron many times, yet there is a point beyond which the addition of titanium does not produce this effect. The production of rustless steel depends upon finding a combination of elements that will hold iron so effectively that it cannot escape and join with oxygen to form rust.

The research laboratories are continually working on questions involving the combinations of elements, but a few simple facts are well known and fundamental both in these investigations and in the practical operation of the foundry. Several of these facts refer to the type of combination in which elements occur.

A number of people in a room may have very different relations to each other. They may constitute a family, or they may be employed together, or be meeting for some purpose, or even be waiting for the same train. Their future association with each other will depend very largely upon the relations between the individuals. The relations between the elements in certain materials are studied in foundry technology because the foundryman must control these relations in order to get the particular qualities he desires in castings.

The combinations of elements with which the foundryman is most concerned are compounds, mixtures, solutions, suspensions, and alloys. The dividing line is not always clear but the distinctions are of importance.

Compounds.—A *compound* is a substance of definite composition the constituents of which have lost their own properties. A compound can be separated into its elements only by chemical change.

The compound, water, has entirely different properties than hydrogen and oxygen of which it is composed. Compounds of chromium, which never occurs in nature as an element, are used in the foundry for their hardening effect upon iron. Other chromium compounds are used by dye manufacturers and painters because of their colors.

Other examples of compounds are the oxides of iron, (including rust, hematite, and magnetite) sulphides which are composed of sulphur and oxygen, iron carbide or cementite which is composed of iron and carbon, the products of combustion, fuel oils and most other fuels, except coke and charcoal, which are very largely made up of the element carbon.

Carbon exists in iron both as an element and in compounds. The free carbon is called graphite or graphitic carbon. The combined carbon is the result of the union of iron and carbon. Total carbon mentioned in the analyses of iron includes both the combined and free forms. Combined carbon and free carbon have different effects upon iron. The addition of substances or the change in procedure which alters the proportion of free and combined carbon affects the characteristics of the iron.

Calcium is important in the foundry though it is rarely seen as an element outside of a chemical laboratory. Lime-

stone is composed largely of calcium carbonate. Quick lime is calcium oxide; slaked lime is produced from quick lime by the addition of water. All the limes are compounds of calcium.

Since compounds contain definite amounts of the elements composing them, every compound whose constituents are known can be represented by a chemical symbol. The *chemical symbol of a compound* tells us of what elements the compound is composed and also the number of atoms of each element in one molecule.

H_2O is the symbol for water and indicates that two atoms of hydrogen are combined with one atom of oxygen in a molecule of water. Fe_3C is the symbol for cementite or iron carbide, indicating that three atoms of iron are united with one atom of carbon in one molecule of cementite.

Carbon dioxide, a familiar product of combustion, is expressed by the formula CO_2 indicating that two atoms of oxygen are united with one atom of carbon to form a molecule. A molecule of carbon monoxide contains only one atom of oxygen and its symbol, CO , shows this fact.

Mixtures.—A *mixture* is a combination of substances in which the constituents retain their original properties, no chemical change having taken place between them. The combination of different sands, of sand with binder, of clay and earth with ores, and sand adhering to iron are all examples of mixtures.

The fracture of cast iron shows it to be a mixture. The general appearance of the fracture is influenced by the proportion of free and of combined carbon. The larger the proportion of combined carbon the whiter the iron is. The presence of free carbon or graphite darkens the iron. Cast iron is thus seen to be both a mixture and a compound.

Solutions.—A *solution* is the mass resulting when a substance disappears in another substance in such a way as to thoroughly mix with it and to be lost to sight as an individual body. Alloys in some cases are considered mixtures and in other cases solutions.

Solutions may occur between substances in any physical state, although a solid dissolving in a liquid is the most common. Syrup, as a solution of sugar in water, and salt in water are

two common examples of solids dissolved in liquids. A gas may dissolve in a solid, as, for example, oxygen dissolves in rubber. A gas may dissolve in liquid as air in water. The air in water is breathed by fish by means of their gills. The substance into which the other disappears is said to be the *solvent*, and the substance dissolved is the *solute*. In the examples just given, sugar, salt, oxygen, and air are the solutes and water is the solvent. When chloroform dissolves oil in the removal of a soiled spot from clothing, the chloroform is the solvent and the oil is the solute.

The time and method of adding certain materials to a foundry charge depends in part upon their solubility under different conditions. Fifty per cent of the ferrosilicon added to a ladle of molten iron may be lost because much of the material neither goes into solution nor into chemical combination. Solubility is affected by temperature and by other factors at least partly under the control of foundrymen.

Suspensions.—A *suspension* is formed when a finely subdivided solid is scattered throughout a liquid but is not dissolved in it. The suspended material will eventually separate out.

A mixture of water and fine sand, and of water and flour, are examples of suspensions. The slag in the cupola before it separates out from the metal is probably in the suspended form.

Colloidal suspensions are more complicated because the particles are smaller than in the ordinary suspensions. The colloidal states of metals are now being studied in a number of metallurgical laboratories; but the subject is far from being understood.

Alloys.—A *metallic alloy* is a combination of metallic elements or compounds which after melting does not separate into two or more layers. When a separation does occur, each layer may be a distinct and separate alloy. All the substances entering into a metallic alloy may not be metals if the character of the final mixture is metallic. For example, carbon is a non-metal but steel is an alloy of iron and carbon, and cast iron is another alloy of iron and carbon. Most of the metals known commercially are either elements or alloys.

Topical Questions

1. Classify the following substances as elements, mixtures, compounds, suspensions, or alloys, or combinations of the preceding:

- (a) Limestone.
- (b) Vanadium.
- (c) Green sand.
- (d) Clay.
- (e) Slag.

2. Name the elements that usually make up each of the materials in the preceding question. An unabridged dictionary gives this information.

3. (a) Name two alloys found in the foundry which are not mentioned in the preceding pages. (b) What elements are found in each?

4. The chemical symbol of magnetite, an important iron ore, is Fe_3O_4 and the symbol of hematite, another important iron ore, is Fe_2O_3 . What do these symbols tell us about the composition of these materials?

5. Give two examples from the foundry not mentioned in this lesson of:

- (a) Compound.
- (b) Mixture.
- (c) Suspension.

6. (a) What are two differences between a suspension and a solution? (b) Mention an example of each, and describe briefly the differences between these examples.

7. (a) What are three important differences between a mixture and a compound? (b) Describe these differences in an example of each.

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1. BRADBURY, ROBERT H., "A First Book in Chemistry," pp. 25-26, 220-221; Chap. IX, p. 505, par. 456.

CHAPTER IV

CHEMICAL ATTRACTIONS

Air and oxygen are frequently referred to as if they were the same gas. A difference is readily seen if a red hot iron wire is first held in the air and then placed in a tube containing pure oxygen. In the air, the wire glows; in the oxygen, it burns just as a splinter of wood might burn in the air. The different effects of air and oxygen on the hot iron wire is due to the lack of chemical attraction between the hot wire and the part of the air which is not oxygen.

Only one-fifth of the atmosphere is oxygen; and oxygen, as we have seen, is very eager to enter into combination with some other elements. The remaining four-fifths of the atmosphere is very largely made up of nitrogen, an element noted for the weakness of some of its chemical attractions or affinities.

This lack of chemical attraction for certain elements makes nitrogen a dilutant of oxygen in the atmosphere. This, like other facts in nature, is of assistance in some places and a factor to be overcome in others. Four-fifths of the tons and tons of air which pass through the cupola every day take no part in the combustion or melting processes but wastefully absorb and carry away heat.

The reluctance of nitrogen to remain in combination with certain other elements is made use of where explosive power is needed as in blasting rock or ore. TNT and nitroglycerin are among the explosives containing this element. While nitrogen is a less active substance chemically than oxygen, it enters into combination with a large number of compounds some of which are of great industrial importance. Ammonia, nitric acid, the nitrates, saltpeter, many fertilizers, muscle, and other body tissues contain nitrogen in various combinations.

Chemical attraction between the atoms in molecules is a very complicated affair which is influenced by many factors.

The relative strength of the chemical affinities between a few elements very largely determines the compounds formed in the cupola and the qualities of castings. A slight change in the proportions of a mixture, the addition of a small amount of a very active element or a change in temperature affecting the chemical attractions between certain elements may result in a decided change in the qualities of the product. As in most places, a desirable change may be accompanied by detrimental ones, and the practical foundryman needs to know as much as he can learn about the tendencies of the elements in the cupola, to unite with each other.

The foundryman needs to know that iron unites readily with oxygen as thoroughly as he knows that 7×7 is 49. His table of chemical attractions is less extensive but more complicated than the multiplication table.

He must know not only that iron and oxygen have a chemical affinity for each other but that silicon's attraction for oxygen is greater than iron's. Then he knows that silicon can be used to take oxygen away from iron. To this knowledge he must add that of the cost and relative advantages of using silicon from different sources, the possible desirability of manganese or other elements that can accomplish this same result and all the other factors that enter into economical production of good castings.

Iron at high temperatures will unite readily with oxygen, sulphur, silicon, carbon, and manganese. Of these five chemical attractions of iron, two (those involving S and O) may be the source of much trouble and avoidable expense in the foundry.

The presence of any considerable amount of sulphur in iron castings and of oxidized iron is always avoided. In getting rid of these two elements, use is made of deoxidizing and desulphuring agents; that is, elements which can take oxygen and sulphur away from iron. Silicon, manganese, and some of the newer elements as vanadium are called "scavengers" in the cupola because they free the iron from oxygen. One effect of manganese in the cupola is the reduction of the amount of sulphur.

The effect of an element upon iron may be produced indirectly, but an understanding of the chemical combinations

involved will make the process very clear. The action of silicon in decreasing the hardness of the iron is an example.

The attraction between iron and silicon is stronger than that between iron and carbon, so a large proportion of silicon causes much of the carbon to be thrown out of combination. It is known that the alloy of iron and carbon has great hardness and that free carbon (graphite) softens iron, so the action of silicon in changing combined to free carbon, decreases the hardness of iron. Silicon is thus said to be a softener although this action is indirect.

The chemical combination of one element with iron is so strong that it is not affected by the temperature of the cupola or the presence of the other constituents of the charge. The amount of phosphorus in the iron of the charge is the amount in the castings, and it has a very definite effect on pouring the molten iron and, later, on the qualities of the castings.

The union of phosphorus and iron produces a very fluid metal. High-phosphorus, free-flowing irons make possible the casting of fine designs of much intricacy and beauty. These castings lack strength, and so the problems of the foundryman continue as he attempts to make the chemical attractions of the different elements serve his purpose. He must keep in mind at one time all the factors that enter into the product he wishes to obtain. Sometimes he controls one element through another, as carbon through silicon; and sometimes he must calculate his mixture to get the chemical compound and qualities he desires.

The chemical changes in foundry processes are greatly modified by the specific temperatures at which the affinities between different elements are most powerful. Thus both manganese and iron possess strong attractions for sulphur. The compound of iron and sulphur is very hard and when present is usually unevenly distributed in castings. Manganese has its greatest power to take sulphur away from iron at the high temperature of the cupola. The addition of manganese to the ladle is, therefore, much less effective in lowering the per cent of sulphur in castings than the addition of the same amount of manganese to the cupola.

The action of all the elements in the cupola charge is dependent upon the combinations they form with each other, just as the events in the government of a country are dependent upon the groupings of the people of the country. These tendencies to form certain groups of compounds and the effect of these compounds upon the qualities of castings will be considered again when the influence of certain elements upon iron is discussed.

It would be a foolish waste of energy for a student to memorize by rote these chemical attractions between the elements in castings. It will be a profitable investment, however, to learn the effects of elements on qualities of castings and trace these foundry facts back to their causes in chemical affinities. This can be made more interesting and more profitable if the young foundryman acquires the habit of learning foundry practices from practical experts and then of attempting to explain, scientifically, these tricks of the trade. In this way, the learner avoids the mistake of thinking of isolated scientific principles and searches for facts that involve many principles, some of which may not be known at present. When a principle and a fact do not agree, the fact is the starting point for further study.

What Slosson says about the scientist in his "Chats on Science" applies equally well to the foundryman studying the theory of his work: "So the scientist has to cut his theory to fit the facts, not only the few facts on which he formed his theory but all the facts, including any that will be discovered in the future."

Topical Questions

1. Explain the burning of two or three familiar substances by the chemical attractions between oxygen and each of three elements.

2. (a) Why is nitrogen a less important element in the control of foundry processes than in the production of by-products in a meat packing plant? (b) How does nitrogen influence the cost of operating a foundry? (c) How much, if any, of the reduction of this cost is dependent upon good management?

3. Why does an oxy-acetylene torch give much greater heat than forced draft on an oil burner when the combustion of the same elements (hydrogen and carbon) is the source of the heat in both cases?

4. (a) In terms of relative chemical attraction, explain the statement that "Silicon sacrifices itself to oxygen in the cupola." (b) Why is this action called a sacrifice?

5. Give an example from the foundry (not already mentioned in this chapter) of a chemical attraction which causes a change in composition only at high temperatures.

6. Why does not iron rust in a very dry place? That is, what condition facilitates the union of iron and oxygen?

7. What is one of the effects upon iron castings of the presence of manganese in the mixture? Explain.

8. Carbon in the graphitic or free state tends to make the grain of iron more open, that is, to increase the porosity. What effect upon the porosity of iron would you expect from the increase of silicon? Why?

9. Why is it said that manganese makes hard iron soft and soft iron hard?

10. In the table below place an X in each square that is exactly below and to the right of two elements that have chemical attractions for each other in the cupola. Each chemical attraction will, therefore, be indicated by crosses in two places.

	Iron	Oxy- gen	Car- bon	Sili- con	Manga- nese-	Phos- phorous	Sul- phur
Iron.....							
Oxygen.....							
Carbon.....							
Silicon.....							
Manganese.....							
Phosphorous.....							
Sulphur.....							

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1. BRADBURY, ROBERT H., "A First Book in Chemistry," pp. 31-47, 300, 315-316, 339-340, 348, 352, 486-492, 516, 557-560.

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1. SLOSSON, EDWIN E., "Creative Chemistry," pp. 276-278.
2. SLOSSON, EDWIN E., "Chats on Science," p. 246.

CHAPTER V

COHESION AND ADHESION

In the previous chapter, consideration was given to the relative chemical attractions that cause atoms to combine in molecules where they lose their own individual characteristics. The molecules of a substance have the distinctive characteristics of the substance. These qualities depend upon the grouping of the atoms just as the characteristics of a country are determined by the parties, parliaments, congresses, and other groups of the people making up the country.

The activity of each country is influenced in part by its relations with other countries. These international relations are like the physical attractions between the molecules of substances, while the relations of people within a country are like the chemical attractions between atoms.

The relations between nations of the same racial stock may be compared to the physical attractions between molecules of the same kind; and the relations between nations of varied races to the attractions between molecules of different kinds.

Cohesion is the attraction between molecules of the same kind. Many metals are hard because of the cohesiveness of their molecules, although hardness is only one of the important characteristics of foundry materials that depend upon cohesion. The cohesive qualities of materials are controlled in many ways in accordance with the requirements of the product.

The attraction between molecules of different kinds is called *adhesion*. The blackening of cores, the use of lead pencils and pens, and hundreds of other everyday operations depend upon this tendency of the particles of different substances to remain in contact with each other. Adhesiveness, like cohesiveness, is subject to a large measure of control; otherwise there would be much less competition among manufacturers based on the relative quality of their goods.

The relative strength of cohesion and adhesion is dependent upon the particular materials concerned. Water will wet, that is, adhere to, most kinds of cloth but the cohesion within the material may be so increased by water proofing that water is shed.

The lack of adhesion between iron and sand prevents dry gagers having much carrying power. Clay wash adheres to both sand and iron, so dipping gagers in clay wash before placing them in the mold is common practice.

The amount of cohesion between the molecules of substances determines the extent of certain important characteristics. Malleability, tensile strength, brittleness, and hardness are of importance in consideration of metals, though these are by no means all the important phenomena arising from the cohesive force within substances.

Malleability is a property of those metals which can be hammered or pressed into thin sheets. Gold, the most malleable metal, can be reduced to a thickness of 1/200,000 in., while iron under certain conditions can be rolled into sheets somewhat less than 1/2,500 in. in thickness. The malleability, temper, and annealing qualities of iron depend upon the composition of the alloy and the arrangement of its molecules. The molecular arrangement is modified by the speed or slowness of cooling. These practices deserve consideration at greater length than can be given in an elementary text.

The tenacity of a material is expressed as its *tensile strength*. This is the cohesive property of a substance which makes it resist being pulled apart. By means of machinery, this property is accurately measured in pounds per square inch. The common metals have a tensile strength varying from 2,000 lb. per square inch in cast lead and 3,500 lb. per square inch in cast tin to 270,000 lb. per square inch with plow steel and 300,000 lb. per square inch with steel piano wire. The internal structure resulting from annealing causes a great change in tensile strength. Unannealed iron wire has an ultimate tensile strength of 80,000 lb. per square inch, but after annealing this may be as low as 40,000 lb. per square inch.

Brittleness is a quality determining the ease with which a substance is shattered by a blow. Of the iron family, unan-

nealed malleable iron is the most brittle, and some kinds of steel the least brittle.

The *hardness* of substances determines the ease with which one is scratched by another. The diamond is the hardest substance known as it is not scratched by anything else. The measure of relative hardness is very important in the metal industries.

Hardness is now under control to within a few points. This control, like all other kinds of technical control, necessitated accurate means of measurement. The most common methods of measuring the hardness of metals are the Brinell and the scleroscope. The part that measurement has played in the development of industrial life will be mentioned later. At this point, it is well to get in mind the structure of the metal which produces hardness. for this is a point of attack in its control.

Brittleness and hardness are both the results of the strength of physical attraction between the particles of which a material is composed, but these qualities should not be confused. For example, dry sand cores are often very brittle and yet they can easily be scratched by the thumb nail.

The cohesion between the molecules within a liquid always produces a *tension* between molecules on the *surface* which is greater than the attraction between the molecules beneath the surface. This accounts for such incidents as the floating of a needle on water. It accounts, also, for the fact that a small drop of liquid which is free to take its form independent of a container becomes spherical. Water on a hot stove and molten lead being poured from a tower are examples. In both cases the particles take a globular form. The action of gravity on a larger mass tends to flatten it out.

When a liquid is in contact with a solid, the molecules of liquid next the container are acted upon by both cohesion and adhesion, adhesion between the different substances and cohesion within the liquid. If the attraction between the molecules of the liquid is stronger than adhesion between the liquid and its container, the liquid draws away from the solid, does not wet it, and forms a convex surface. Mercury is an example of this.

If adhesion is the stronger force, the liquid wets the solid, and the particles on the edge tend to rise a little above the level of the remainder of the liquid. This is *capillary action*. If the spaces in which the liquid may rise are very fine, the force of capillarity may raise the liquid to a considerable distance. The use of lamp wicks and absorbents of all kinds depends upon capillarity. Sand is usually allowed to lie on the floor some time after water has been added to the heap in order to give time for the moisture to become well distributed. Wetting down a sand heap is much like dropping ink on a blotter, capillary action taking place in both cases.

Topical Questions

1. What foundry product is advertised for its adhesive quality? Explain.
2. Mention a claim for the products of your plant which depends upon their cohesiveness. Explain.
3. In terms of cohesion and adhesion, explain water running off a heap of burned sand.
4. (a) What force holds the sand to the gagers, hooks, and bars when they are coated with bonding materials? (b) What force holds the rammed sand together in a mass?
5. (a) What force holds the sand when bonding material is not used? (b) What do you understand by "bond" as the term is used in the foundry?
6. Is a green core held together by the same kind of force that holds it together after it is baked? Explain.
7. Explain the use of soldiers in supporting green sand pockets.
8. Why are gagers dipped in clay wash before they are placed in molds?
9. Why may the use of too strong a vibrator tear up the sand in the mold?
10. When cohesion is partially overcome by the application of heat, what does this prove with regard to heat?
11. (a) Does an increase in temperature always lessen the force of cohesion? If not, give examples. (b) If it does, state the rule or principle involved.
12. (a) From your own experience or general reading, arrange the following materials in order of hardness beginning with the softest one: Iron, lead, diamond, steel, copper, tin, brass, nickel-steel. Then check your list by means of a table in a technical reference book. (b) What point is brought out beside the relative hardness of the different elements and alloys?

13. (a) Give an example of the difference between brittleness and hardness. (b) Explain this difference in terms of physical attractions between molecules.

14. One end of a towel is left in a lavatory into which a faucet is leaking and the other end hangs free over the side. (a) What happens to the towel and the floor under it? (b) Why?

15. The moisture in cloth will become fairly well distributed, for example, when a damp coat is laid over other garments; but there may be quite dry and wet spots in the same pile of sand. Explain this difference.

16. Mention two uses of abrasive agents in the foundry and explain their action in terms of cohesion, adhesion, and relative hardness.

Text References

1. HIGGINS, LOTHROP D., "Introductory Physics," pp. 12-14, 28-32.
2. SEARS, FREDERICK E., "Physics for Secondary Schools," pp. 102-107.

CHAPTER VI

CONTRACTION, SHRINKAGE, AND EXPANSION

The attraction between particles of the same substance which was discussed in the last chapter, is a force with which the foundryman must constantly reckon. If his reckoning is incorrect, he will have much difficulty from such sources as porosity, shrink holes, and weakness where heavy and thin sections meet. If he lacks understanding of the principles involved, he may attempt to overcome the difficulty by means as ineffective as trying to put out a fire with turpentine instead of water.

Contraction and shrinkage are the results of the action of the force of cohesion. Cohesion, as has already been learned, is the force that pulls together molecules of the same kind. Although contraction and shrinkage are parts of the same process of lessening in size and are influenced by many of the same factors, foundrymen frequently think of different things when the two terms are used.

Contraction is thought of in the foundry as the decrease in size which makes the casting smaller than the pattern. Shrinkage calls to mind spongy places or even holes in the interior of the casting. As will soon be seen, the formation of these open spaces is due to cohesion pulling the mass together as truly as is the contraction of the entire mass due to cohesion.

Contraction is the lessening in size of a solid as it cools. The amount of contraction for each degree in change of temperature varies with the substance but it is definite for each substance. The decrease in length with the decrease in temperature is the same as the increase in length with rising temperature. This increase in length is referred to as *linear expansion*. The figures for linear expansion have been determined for all the common metals.

It must be remembered that metals, as they are cast, are in most cases alloys, and the exact composition of alloys is apt to vary. The practice of casting to size is growing, and this may mean that the finished casting must measure to within 2/1,000 in. of the specified size. Where this degree of accuracy is required, the amount of contraction is tested daily and the mixture and other conditions maintained so as to insure that the finished castings will not need to be scrapped because of variation in size.

Where machining to size is allowed, calculations can be made for the average amount of contraction. The average contraction of cast iron is considered to be 1 per cent or approximately $\frac{1}{8}$ in. per foot; but with different irons of extreme variations in composition and quality, the contraction may range from $\frac{1}{10}$ to $\frac{3}{8}$ in. per foot. The tables for linear expansion of metals must therefore always be considered as averages.

The following figures are taken from the table on page 1245 of the fifth edition of "Machinery's Handbook."

TABLE I.¹—LINEAR EXPANSION OF COMMON METALS

Metal	Linear Expansion per Unit Length per Degree Fahrenheit
Aluminum.....	0.00001234
Brass, average.....	0.00000957
Bronze.....	0.00000986
Copper.....	0.00000887
Iron, cast.....	0.00000556
Iron, wrought.....	0.00000648
Lead.....	0.00001571
Steel.....	0.00000636
Tin.....	0.00001163
Zinc.....	0.00001407

Expansion and contraction have been spoken of as linear. Solids expand or contract in three dimensions and the change is volumnar rather than linear. The coefficient of expansion of volume is considered sufficiently accurate when stated as three

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times the linear coefficient of expansion or expansion per unit of length.

Provision is made in various ways for the normal contraction of cooling metals. Patterns are made larger than the castings, yielding cores or molds are used and other arrangements made. All these allowances must take into consideration other characteristics of the metal. For instance, figures in the preceding table indicate that brass can be expected to contract in cooling nearly twice as much as iron. The foundryman knows not only that brass tends to contract a considerable amount in cooling, but also that it is very weak when hot. He knows from experience, if not from reasoning, that a non-yielding core in a large brass casting is certain to produce a crack. To prevent this, he may put sawdust in the core, as sawdust is burned away by the heat of the molten brass.

Contraction should be normal in amount and evenly distributed. A lack of sufficient contraction may lead to the formation of blow holes or of dangerous stresses within the metal. Fractures, perhaps microscopic in size at first, may be produced whenever the cohesive forces of the particles in cooling metal are not evenly and completely adjusted throughout the mass. Annealing, during which the molecules rearrange themselves, lessens the contraction stresses.

Before leaving the subject of contraction and expansion caused by changes in temperature, it should be noted that water in cooling does not follow the general rule of an uninterrupted decrease in volume. As water is cooled, its volume and, therefore, its density decreases until the temperature of 39° F. is reached when a regular increase appears. The result of this, as can easily be seen, is that the water at the bottom of a frozen lake or stream tends to remain several degrees above the freezing point. This fact is mentioned here because in learning a general tendency, such as the decrease of volume with temperature, it is well to keep in mind the possibility of exceptions. These exceptions are never chaotic but rather are applications of other laws.

The fact that water during cooling departs from its regular course of contraction just before freezing should prepare the foundryman to expect possible irregularities in the change

of volume of metals during their cooling and setting. In fact, some metals show more irregularities than water because more and different factors enter in. Two, and even three periods of actual expansion have been accurately noted during the first stages of the solidification of iron of different composition while other iron does not show any increase. These expansions occur between contractions. Complex chemical changes probably are associated with these irregularities in volume. These brief periods of minor expansions do not seem to enter into the practical problems of shrinkage and contraction, although they may account for the superiority of certain mixtures for specific requirements in casting metals.

The changes which take place within metals during contraction have been described before the changes occurring during shrinkage because most people are familiar with the reduction of volume in solids produced by lowered temperatures. The worker in the foundry is familiar also with the decrease in volume as the molten metal becomes solid; that is, as it changes from one physical state to another. This is referred to as *shrinkage* to distinguish it from contraction.

As the molten metal rushes into the mold, the portion which comes in contact with the surface of the cool mold at once begins to set. A solid shell is thus formed on the outside of the casting. This shell of solid metal by the force of cohesion draws liquid metal toward itself, and of course this comes from the center where the metal is most fluid. This process continues, the outer part setting, contracting, and getting all the material needed for this contraction from the inner liquid portion. If there is not sufficient metal to completely fill the mold, the part which solidifies last will suffer. As it sets there will be no supply from which additional metal can be drawn. A spongy or coarse mass results or even large holes may be formed.

This shrinkage of metal as it sets, makes necessary an additional supply of molten metal, and this is furnished through feeders and risers. If the metal in the riser should set, this fresh supply is cut off. To prevent this, a churning rod may be used to keep the metal liquid and more hot metal may be added so that it will fill the center of the mold.

Where the supply of metal has been insufficient to make good the loss from shrinkage, splinters of metal, looking like the fragments of a board which has been pulled in two, may be found in the interior of the casting. This pulling force is, of course, the cohesion of the metal in the outer solid shell of the casting contending for the supply of metal in the center. A large amount of shrinkage with no lack of metal in the center, as would be expected, produces a close or fine grained casting. Where a fine grain of casting is desired, the feeding must insure plenty of iron to make up for the shrinkage. If this is not possible, then a mixture must be used in which there will be less shrinkage.

The foundryman meets the problems of shrinkage in various ways according to the situation.

The design of the pattern sometimes has to be changed in order to get a satisfactory location for risers and gates. The gate should be located as far as possible from the point of shrinkage so as to reduce the temperature of the iron by the time it reaches this point. This allows a part of the contraction to take place before the metal reaches the point of shrinkage in the casting and so a smaller supply of liquid iron will be drawn from the point of difficulty. A difference of even 300° F. may overcome the difficulty. This accounts for the rule that the first iron in should go to the place where shrinkage is apt to occur.

It is not safe practice, however, for the foundryman to try to locate the entire responsibility for shrinkage difficulties in the designing or pattern department. There are several methods by which he can overcome shrinkage troubles without any change in the design of the pattern.

If it be possible to place the pattern in the mold so that the point where shrinkage has occurred is quite low, then the immense pressure and the tendency for metal to be drawn from the top may be sufficient to close up the grain and prevent any sponginess of structure.

A riser may be placed directly over the point of shrinkage and be kept open by means of a churning rod. Hot metal can then be fed through the riser as long as a supply is needed.

If these other methods of overcoming shrinkage troubles are impractical, a chill may be the device that will do the work. Shrink holes result from the different parts of the casting setting at different times and, as has been mentioned, the part to set last has open spaces because it furnishes iron to the other parts of the casting. A chill will hasten the setting of metal so it is placed near the point of shrinkage and against the section which otherwise would set last.

Open spaces frequently occur when a heavy section adjoins a light section. A chill near the heavy section hastens its setting, and as the two sections set at the same time shrink holes are prevented.

The use of chills in some cases requires a careful consideration of the whole situation as the following incident illustrates.

Castings for containing liquid under pressure were giving difficulty by leaking at a narrow section. The leaking was attributed to open grain if not to actual shrink holes.

The iron was cast thicker at the narrow section and no improvement resulted. This should have been expected for two sponges are little better than one in stopping a leakage. The original size of section was then used and a chill placed on the outside, but the difficulty continued. When liquid enters metal of porous structure, it can travel great distances. In this case, the place of leaking was simply changed.

The chill was then placed on the inside and the leaking ceased. The reason was simple. The water was unable to enter through the close grained iron produced by the chill. Even if shrinkage did continue in the interior of the iron it did no damage in this case. The water did not get through to the center and the castings stood the test of permeability.

Chills cannot be depended upon to prevent all shrinkage difficulties even when their use is convenient. If the casting is to be machined at this point, a chill will make the surface too hard. But the surface is not the place where the chill is needed. The finer grain produced by the chill is needed in the interior where the shrinkage occurs, and the chill can be transferred from the outside to the interior by means of a good conductor of heat. Nails serve this purpose. As many

nails are used as can be placed in the sand, the heads of the nails in the place where the shrinkage has occurred.

Finally, the prevention of shrinkage by a change in the mixture is to be considered. If nothing more can be done to supply all the metal needed to make a dense, even-grained casting, the mixture can be so changed that there will be a less amount of contraction. This, of course, means a coarser grain throughout the entire mass, but an evenly porous casting is preferable to a fine-grained casting with open spaces in the center. Changing the mixture to prevent shrinkage requires a knowledge of the effects of the different elements upon this quality of metals.

The student of foundry technology, after his study up to this point, should have sufficient knowledge that he can reason out for himself the effects of certain elements upon the shrinkage and grain of cast iron. It hardly needs to be said, though, that since so many influences bear upon any result, this theoretical reasoning needs to be checked by facts.

Let us see how far the effect of silicon and manganese upon the shrinkage and grain of gray iron castings can be inferred from facts already known.

Both silicon and manganese affect the qualities of iron through their influence on the proportion of carbon in the combined and free states.

All the carbon in molten iron is in the combined form. In white iron, the carbon remains in this state. As gray iron cools, a part of the carbon separates out as graphite. The amount which separates out depends upon the rate of cooling and the composition of the iron. As is quite evident, if the metal cools quickly there is little time for this separation to occur and the proportion of combined carbon is high. During slow cooling, a large part of the carbon separates out.

Silicon lowers the amount of combined carbon while manganese tends to increase it when present in sufficient quantity. The reverse is true regarding the amount of graphitic carbon; that is, silicon increases the proportion of graphitic carbon and manganese decreases it.

The flakes of graphitic carbon can be expected to decrease the cohesion within the iron, and shrinkage depends upon the action of a strong cohesive force. Theoretically, the presence

of graphitic carbon should decrease shrinkage. This is in keeping with the facts. It is a common observation that graphite decreases shrinkage of iron and tends to produce an open or coarse grain. Combined carbon has exactly the opposite effect. It is said to produce a fine grain.

Knowing the effect of silicon and of manganese on the proportion of graphitic and combined carbon in castings and the influence of carbon in these two forms upon shrinkage and grain, it is easy to predict certain influences of these elements and to understand the observed facts. If a considerable amount of total carbon is present, silicon decreases shrinkage and produces a coarser grain. This is the indirect result of silicon's production of graphitic carbon. If the total amount of carbon is not increased, manganese has the effect of keeping carbon combined and consequently of increasing shrinkage and producing finer grained castings. This could hardly be otherwise since both these elements act through carbon. Later we shall learn of other chemical attractions of silicon and manganese of interest in the foundry which do not relate to carbon.

The effect of sulphur should not be overlooked at this point. Sulphur has long been considered, in some quarters, as the plague of the foundryman. There are some indications just now that attention may be given to the possible good effect of sulphur under certain conditions. In any event, it is worth while to keep in mind that sulphur increases the shrinkage of iron and helps to close the grain making the structure closer.

Shrinkage and contraction are a continuous process which begins when metal is poured and is finished only when the castings have reached their final volume at ordinary temperatures. Internal rearrangements as to structure are involved throughout the process. The foundryman's problem is to select the constituents of the charge, select patterns of the right design, and pour the metal so that, finally, the castings will be free from dangerous internal strains, shrink holes, and other defects.

Topical Questions

1. (a) What is meant by the coefficient of expansion? (b) Give an illustration from this chapter. What unit of temperature is used? Of length?

2. (a) In terms of the coefficient of linear expansion, what is the coefficient of expansion for volume? (b) Is this approximation more or less than the accurate calculation would be? Why? (The answer involves the cubing of a binomial and the squaring and cubing of a very small decimal.)

3. What principle is made use of in constructing delicate machinery (such as the balance wheel of a watch) so as to keep it in good working order at different temperatures?

4. What defects are sometimes prevented by equalizing the rate of cooling of different parts of a casting? Explain.

5. How does the dullness of the metal poured affect the amount of shrinkage? Explain.

6. What is one important reason for the general rule that all parts of a casting should solidify as nearly as possible at the same time? Mention one method of obtaining this result.

7. What is the reason for the rule that the feeder should solidify last?

8. Too small a riser will obviously injure the qualities of castings. What are two of the factors that should keep a foundryman from having the risers too large?

9. (a) Iron begins to set at approximately 2,100° F. How great a contraction would this produce, calculated in eighths of an inch per foot? What is usually allowed in practice? (b) Why do these two figures differ?

10. Why may a mold blow if its surface has been rammed too hard?

11. Why is oil sometimes used to test castings which appear to be perfect when finished?

12. Why do shrinkage troubles almost always appear in the part of the casting in the cope and rarely in the drag?

13. Oxidized iron sets quickly. (a) Trace the effect of this fact through to the phenomenon of interior shrinkage. (b) Explain.

14. Since iron flows into molds through gates and since additional iron may be added through risers, why does the foundryman attempt to lessen shrinkage by gating as far as possible from the place of shrinkage and putting a riser as near as possible to the point of danger?

15. (a) What effect upon the fineness of design possible on the surface of a casting can be expected from $\frac{1}{100}$ in. expansion as the metal begins to set? (b) With what composition of iron has this expansion been observed? (c) For what purpose is this iron frequently used?

16. A foundryman had tried unsuccessfully to prevent leakers in cylinders which were to hold water under pressure. Finally, he cut down the silicon in the charge, reasoning that low silicon would mean denser iron and so less leaking. (a) What was the result? (b) Explain.

17. (a) What is an important essential in all annealing of metals? (b) What is the effect of this upon any two important qualities?

18. In the casting of gray-iron containers for ammonia gas under pressure, 25 per cent of steel scrap was used. There was much shrinkage

and leakers were frequent. More steel was added to the charge. What was the effect upon the amount of shrinkage and the defects? (Steel scrap reduces the percentage of silicon in iron castings.)

19. If a foundryman finds he cannot feed a casting enough to prevent a spongy interior, what can he do to avoid this condition?

20. Arrange a table to show, by means of plus and minus, the effect of five elements in the charge upon the shrinkage and porosity of grain in iron castings.

Text References

1. HIGGINS, LOTHROP D., "Introductory Physics," pp. 164-167.
2. MOLDENKE, RICHARD, "Principles of Iron Founding," pp. 55-58, 132-146, definitions of terms in this chapter, pp. 459-463.
3. SEARS, FREDERICK E., "Physics for Secondary Schools," pp. 302-307.

CHAPTER VII

ACIDS, BASES, AND SALTS

A man is burned by caustic potash, and diluted vinegar is used in washing off the potash. Castings to be galvanized, after being pickled in hydrofluoric acid, are washed in a bath of dilute alkali, followed by rinsing in hot water. The bricks in a cupola are cut down in one heat and the technical expert finds that the basic slag has had a corrosive effect on the acid refractory materials. The cream is slightly sour and it is sweetened for table use with a little soda, or with more soda it is used in the kitchen in making light foods which have no suggestion of acid taste.

All these incidents and thousands of others in daily life depend upon the attraction of two kinds of substances for each other. These substances are acids or sour things and alkalis or basic materials.

When acids and bases act upon each other they form salts. A large part of the materials dealt with in industrial life are salts in the sense that they have been formed by a combination of acids and bases. Because acids and bases tend to neutralize each other, salts usually, but not always, produce neutral solutions, that is, solutions which are neither acid nor alkaline. Naturally, a salt of a very strong alkali and a weak acid would not produce a neutral substance, for in chemistry, as elsewhere, forces must be equal to neutralize or cancel each other.

In the popular sense, acids are sour things since dilute acids have the taste associated with vinegar or lemon juice. Bases are not so easily identified popularly, although all are familiar with a number of them such as soda, lime, lye, potash, and ammonia. A soapy feeling is characteristic of alkalis.

From a chemical standpoint, acids are hydrogen compounds and bases are hydroxides. The chemical symbols explain

these statements. H_2SO_4 is the symbol of sulphuric acid, HNO_3 of nitric acid, and HCl of hydrochloric or muriatic acid.

The group of elements (or "radical" as such a group is called in chemistry) designated by OH is present in all bases. Hydroxyl, OH , like one's hand or foot does not occur in nature apart from the body in which it functions. The presence of hydroxyl explains the statement that bases are hydroxides. Thus, the symbol for caustic potash is KOH , the technical name for which is potassium hydroxide. The symbol of ammonium hydroxide (or "ammonia" as it is commonly called) is NH_4OH , and of sodium hydroxide, NaOH . The latter alkali in solution is sometimes called "soda lye" and in the solid form, "caustic soda."

The chemical symbol of a salt indicates which acid and which base have united to form the salt. Our common table salt, NaCl , is produced when the alkali, sodium hydroxide (NaOH), and hydrochloric acid (HCl) are brought together in the correct proportions.

Burnt fire clay is a neutral substance that sometimes satisfies a decided need in the cupola. The neutrality of this substance depends on the fact that it contains alumina, a basic substance, and silica which is acid in character. The foundryman may plan to produce a neutral slag by bringing acid and basic materials together in such a way that they will combine chemically.

A substance may be neutral for another reason than its structure as a salt. Its neutrality may be due to its having no chemical attractions for either bases or acids. Carbon in its various forms is a neutral substance of this kind.

There are several tests for distinguishing between alkalis and acids. Litmus, a specially prepared paper, turns blue in an alkaline solution and red in acids. The color of the slag in the electric basic-lined steel furnace indicates to the men in charge the composition of the molten mass. The dark-green or black slag can be made white by adding a small amount of powdered coke or coal which brings about chemical changes, thus indirectly altering the reaction of the slag. Spring well describes this phenomenon. This change of color according to the acidity or alkalinity of substances is made use of

in many industrial operations, as well as in sleight of hand performances.

The acids used as liquids in the foundry include sulphuric acid or vitriol (H_2SO_4), hydrochloric or muriatic acid (HCl), nitric acid (HNO_3), and hydrofluoric acid (HF).

Sulphuric is probably the acid best known by name to a practical foundryman; though, as will soon be seen, some familiar substances he does not think of as acids really belong in this class.

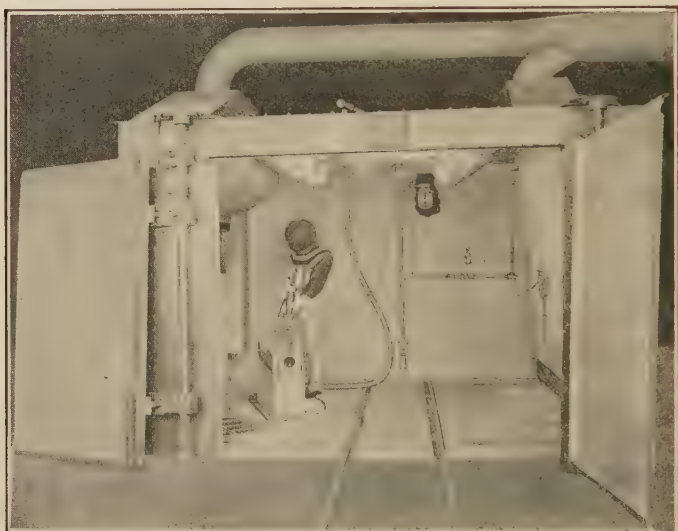


FIG. 1.—The sand blast is being made safe through constant research.
(Courtesy of the Pangborn Corporation.)

Acid is sometimes used in the cleaning of iron castings that cannot be put through the tumbler. Castings of brass and copper alloys are frequently cleaned by means of acid.

The pickling or cleaning of iron castings by means of acid, usually sulphuric, is one of the operations in the foundry that is being displaced by improved methods. The hydraulic cleaning of castings is a recent innovation which has much in its favor. The addition of sand to the water gives an abrasive action which produces a good surface on metal and therefore makes the process more effective.

The cleaning departments of foundries have been the subject of continual research for many years. As production has

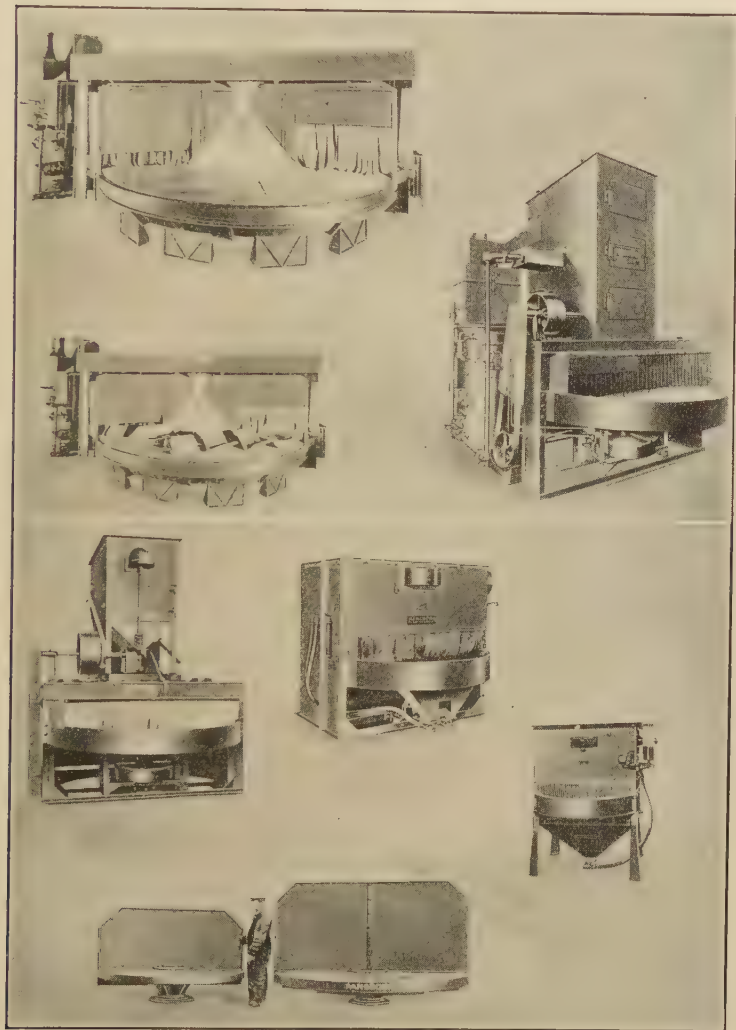


FIG. 2.—Eight types of cleaning devices commonly seen in foundries. (Courtesy of the Pangborn Corporation.)

been multiplied and strenuous labor reduced in melting and molding, cleaning problems have grown. From crude hand

methods involving much labor, research and experiment have led to the development of equipment which is at once productively efficient and humanly commendable. When one views the operation of some of the latest cleaning devices and then sees in other foundries outworn practices that are laborious, expensive, and often dangerous, he is aware of the rapidity with which the foundry industry is advancing. Space does not permit the discussion, in a special chapter which the subject justifies, of the cleaning of castings. It is, therefore, referred to, briefly, in connection with acids because acids have been widely used in the cleaning of some kinds of castings. The student is urged to investigate more fully using the references on this important foundry detail.

The use of sulphuric acid in pickling has several disadvantages, one of which is the production of fumes. These fumes are obnoxious to the workers and produce rust on the machinery. Shafting may be so rusted that its term of service is greatly shortened.

The pickling process, as it is used in foundries, illustrates several characteristics of sulphuric acid which are worth understanding. Even if hydraulic cleaning replaces pickling, sulphuric acid will continue to be a useful agent in industry.

Full-strength sulphuric acid is an extremely dangerous liquid to handle carelessly. It will burn the skin and char wood like a white-hot iron. A large amount of heat is produced when water and strong sulphuric acid are mixed, so the use of water in treating a burn from strong sulphuric acid is exactly the wrong procedure. The fact that alkalis and bases neutralize each other is made use of in caring for sulphuric acid burns, though, of course, care must be exercised that the alkali is not so strong that it adds to the damage.

An approximately 10 per cent solution of H_2SO_4 is used in the pickling process: 10 parts sulphuric acid and 90 parts water. This strength of acid has a much greater effect upon castings than the strong acid. One who has put out a fire by too much fuel or too much draft can readily understand that an excess of a necessary substance may not only be useless but detrimental. It is a case of just enough to facilitate a certain chemical reaction and no more.

The chemical reaction in the cleaning of iron castings by dilute sulphuric acid is similar to a reaction that is familiar wherever iron is exposed to moist air. This is the formation of iron rust.

When iron castings are pickled in H_2SO_4 , an oxide of iron is formed under the adhering sand particles. This oxide carrying the sand with it falls off in sheets or it may be removed mechanically by a stream of water. A warm solution of the acid is necessary, for the cold dilute acid does not have any effect on the metal under the conditions of pickling.

Castings to be pickled are sometimes placed in baskets, lowered into tanks and allowed to remain for an hour or more. They are then drained and washed with a spray of hot water. Sometimes a base is used to get rid of the acid more quickly.

In another method, the castings are held in a lead lined tank while a workman wearing rubber gloves, rubber apron, and boots uses a copper dipper to pour the dilute acid over the castings. They are then drained upon a lead lined platform.

Hydrofluoric acid is sometimes used in the cleaning of castings, more frequently those of a copper alloy than of iron. It illustrates an important characteristic of acids, though it is to be expected from the knowledge of relative chemical attractions between elements. The radicals or groups of elements characteristic of various acids and alkalis act like the elements in having affinities of varying strengths for other elements or groups. Each acid tends to make its own characteristic combinations. In regard to other substances it may be quite inactive chemically.

Hydrofluoric acid attacks silica very readily while sulphuric acid does not. Just the reverse is true of these acids regarding iron. The sharp edges of iron castings are quickly eaten away in a bath of sulphuric acid but iron can be left in hydrofluoric acid for days with no change. The result of these chemical affinities is that an iron casting covered with sand can be quickly cleaned in hydrofluoric acid which dissolves the sand but does not attack the iron (Moldenke, page 170). Another result is that sulphuric acid can be stored in glass,

but hydrofluoric acid must be kept in containers of paraffin or other material not composed of silica.

The foundryman who is striving to understand the chemical changes in his laboratory, the foundry, does not have a simple task in dealing with acids and bases. He must recognize in the cupola the strongly acid and basic character of certain elements which he is accustomed to observing outside the cupola as neutral substances. It is quite easy to recognize as acids or alkalis the liquids usually known as corrosive or caustic substances. It is not so easy to recognize the true character in the cupola of iron oxides or phosphorus. It may help, to remember that the metals form basic compounds and that the acids are compounds of non-metals. This would lead one to expect that which is a fact: iron oxides are basic, and phosphorus tends to make the mass acid.

Almost everyone is familiar with the action of sulphuric acid or "vitriol" as it has been called, so the foundryman would expect sulphur to have an acid effect under favorable conditions. One such situation occurs when some of the sulphur in the charge is burned. The product formed in burning sulphur unites with water vapor in the air and the acid thus produced attacks the exposed iron work.

Silica is quite unlike sulphur in its suggestion of an acid. Silica as a constituent of quartz rock and of sand suggests an inert substance. In the molten mass in the cupola, silica has an entirely different aspect for it acts as an acid. In fact, silica is called the "acid of the metallurgist" just as vinegar might be called the "acid of the kitchen."

Before the difference between acid and basic linings of furnaces and converters was understood, high phosphorus iron could not be used in making steel.

The Bessemer converter is credited with having been an essential part in the development of the steel industry with all that this has meant to transportation and other parts of modern life. Yet it failed, at first, with high phosphorus iron ore, the ore upon which Germany's industrial system has depended. It was only when metallic oxides, which are basic in character, were used in the lining of furnaces and in the fluxes that the phosphorus could be reduced in high

phosphorus iron sufficiently to permit the manufacture of steel. The earlier converters and openhearth furnaces had all been silica lined and, therefore, were acid. By a complex chain of chemical reactions, the phosphorus was retained in the iron.

When basic linings and fluxes are used, the phosphorus is forced into the slag, where, as fertilizer, it can be made to serve a useful purpose. The iron with lowered phosphorus can then be converted into steel. The careful selection of basic or acid refractory materials and fluxes makes it possible to produce practically identical steel products from iron high or low in phosphorus. This is only another example of the technical control of materials upon which industrial progress is based.

Basic refractory materials are less used in iron than in steel foundries but it is well for any foundryman to keep in mind the character of the materials he is using.

Lime in its various forms, magnesia, alumina, and oxides of iron are all basic in character and are used where heat resistance is required. Neutral refractory materials include plumbago and burnt fire clay. Heat resisting foundry materials which are acid in character include ganister, flints, and silica, all of which are forms of silica. These acid refractories are used when low phosphorus iron ore is used in blast furnaces producing pig iron for steel-making purposes.

Topical Questions

1. A bridge over railroad tracks had to be replaced in a certain city because of the corrosive action of an acid. Explain.
2. Compare the action of the different acids in cleaning castings.
3. Where, outside of the cleaning department of a foundry, are acid substances used to clean metals? What is the acid in each case mentioned?
4. Why may lime be thrown upon wood where sulphuric acid has been spilled?
5. In treating an acid burn, is carron oil any better than olive, linseed, or any other good oil? Why?
6. Carron oil is named from the Carron Iron Works in Scotland where it was first used. How could this be accounted for?
7. From the standpoint of chemical affinities, explain the use of lead, copper, and rubber in the pickling process.

8. What are three forces which must be resisted by the refractory material of a cupola?

9. What can be done to prevent acid and basic sections of a furnace lining from fusing together? (Moldenke, p. 278.)

10. Give the name of each of the following and state whether its presence tends to make the reaction of the cupola charge acid or basic: (a) CaO, (b) SiO, (c) MgO, (d) Al₂O₃, (e) SO₂, (f) Fe₂O₃, (g) MgCO₃, (h) Fe₃P.

11. Name three factors involved in cleaning castings which, in your opinion, deserve special attention.

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3. SPRING, LAVERNE W., "Non-technical Chats on Iron and Steel," 2d. Ed., 1927, pp. 139-140, 155-156.

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1. HALL, JOHN HOWE, "The Steel Foundry," "Digging Out and Cleaning," pp. 269-272.

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PART II
SOME PHYSICAL PROPERTIES

CHAPTER VIII

MEASUREMENTS

The present time or age is sometimes called the "Mechanical Age" and the present civilization is referred to as "Scientific Civilization" because of the great advancement made in the past 200 years in science and the mechanic arts. This advance, which constitutes the chief difference between conditions today and those of ancient times, is due very largely to the development of more and more accurate methods of measuring such factors as time, length, mass or weight, and temperature.

In former times when scientific knowledge was very scant, the standard measures were selected in some arbitrary manner; for example, the English yard was the length of a man's outstretched arm, measured from the middle of his chest. The particular man selected is said to have been King John, who reigned about 700 years ago. The yard had been used centuries before that, but was then officially fixed by the government for the first time.

The *metric system* is the outgrowth of a plan originated by the French government to establish a standard which would not depend upon some arbitrary figure such as the length of a man's arm. The French scientists proposed to measure carefully the quarter circumference of the earth from the equator to the North Pole and to divide that distance into ten million parts. One such part was found to be about $3\frac{3}{8}$ in. longer than an English yard and was called a meter. After the meter had been officially adopted and its length standardized, it was found that, owing to an error in their measurements, it was not a true ten-millionth part of the quarter circumference of the earth. The convenience of the metric system lies in the ease with which dimensions may be converted from one unit to another by merely changing the decimal points, since

the whole system is arranged on the decimal plan. In English-speaking countries, the metric system is used in scientific work only.

In industrial plants, the measures in most common use are those of time; mass or weight; extension, which includes length, surface and volume; and temperature.

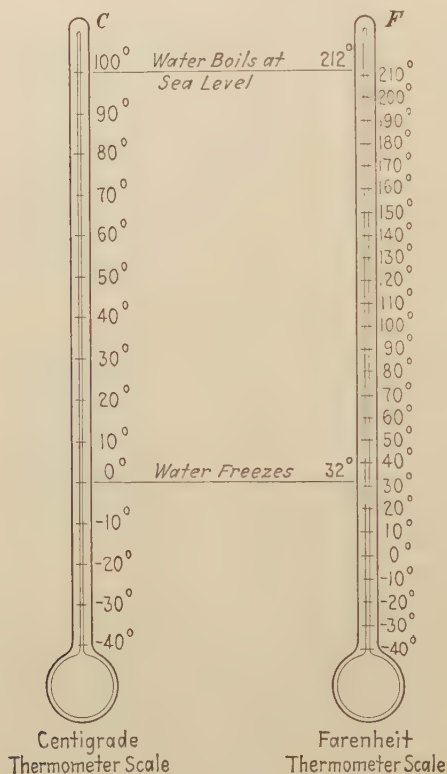


FIG. 3.

The *second* is the unit of time used in technical work. It is defined as the eighty-six-thousand-four-hundredth part of a mean (average) solar day. It is also defined as the length of the beat of a pendulum of certain length under certain specific conditions. It is a well established, world-wide standard.

The unit of mass or weight for the United States and the British Empire is the *avoirdupois pound*. This unit of weight may be connected with the other units of the system by the fact that a cubic foot of pure water at 39.1° F. weighs 62.4245 lb.

The unit of extension is the *foot*, which is one-third of a standard yard. The *linear foot*, *square foot*, and *cubic foot* are, respectively, the units of *length*, *surface or area*, and *capacity or volume*.

Two different units are in use for the measurement of temperature. The one commonly used in America and the British Empire is the *Fahrenheit degree*. In some other countries and for most scientific work, the unit is the Centigrade degree. The Fahrenheit temperature scale is an arbitrary scale in which the so-called *zero* is 32° below the freezing point of water under certain specific conditions. On this scale, pure water boils at 212° at sea level. The Centigrade scale takes the freezing point of water as zero and the boiling point as 100°. Since there are 180° on the Fahrenheit scale between the freezing and the boiling points of water and only 100° on the Centigrade scale, it is plain that 1° F. = $\frac{5}{9}$ ° C. or 1° C. = $\frac{9}{5}$ ° F. A comparison of the two scales is given in Fig. 3.

The so-called English system is sometimes referred to as the *foot-pound-second* system. The metric or French system is commonly called the *centimeter-gram-second* system. The centimeter, or one-hundredth part of a meter, is the common unit of length used in mechanical and scientific work throughout the world.

Topical Questions

1. Describe three methods of measurement commonly used in foundries.
2. What department of a foundry would be most affected by inaccurate measurement of time? Length? Mass or weight? Temperature? Explain in each case.
3. What uses are made of the metric system of measurement in foundries?
4. What is a solar day?
5. What effect, if any, does altitude have upon foundry temperatures and practices?

6. (a) Write the formula for changing Centigrade degrees to Fahrenheit. (b) Use this formula in the following problems:

$$100\text{ C.} = ?\text{ F.}$$

$$17\text{ C.} = ?\text{ F.}$$

$$0\text{ C.} = ?\text{ F.}$$

7. (a) Write the formula for changing Fahrenheit degrees to Centigrade. (b) Use this formula in the following problems:

$$210\text{ F.} = ?\text{ C.}$$

$$98\text{ F.} = ?\text{ C.}$$

$$30\text{ F.} = ?\text{ C.}$$

CHAPTER IX

WEIGHT, DENSITY, AND SPECIFIC GRAVITY

Weight.—If a piece of metal, stone or other material is held in the hand, a pressure toward the earth is felt; if the material is released, it falls to the ground. By means of a spring balance or pair of scales, the amount of pressure the object exerts may be measured in pounds or other units. This pressure is due to the force of gravity. All objects on the earth's surface are attracted in this way by the earth. The amount of attraction measured in pounds or other units is called the *weight* of the object.

This attraction which the earth exerts is not the same for all substances. If accurate cubes were made, 1 in. on each edge, from iron, copper, lead, aluminum, wood, etc., it would be found that hardly any two would weigh exactly the same. Some would be quite heavy, others light. The quantity of matter in one of these cubes is called its *mass*. The word "mass" is used in different senses. In these chapters the mass of a body refers to the quantity of matter it contains. This is the usual meaning in texts on physics.

The measured attraction of the earth for the mass in one of these cubes is called its *weight*. *The mass and weight are proportional*. Notice again the definition of mass, and it will be seen that it must remain the same always, whatever the location of the cube; while the weight, or gravitational attraction, may vary slightly in different parts of the earth, being greatest near the poles and least near the equator. A mass of 1 lb., if it could be removed entirely from gravitational attraction, would weigh nothing, although its mass would remain unchanged.

Density.—The weight of a unit of volume of any substance is called its *density*. Density is expressed as pounds per cubic foot, pounds per cubic inch, or, in the metric system, grams per cubic centimeter. Thus, the density of cast iron

is 449.2 lb. per cubic foot; the density of water is 62.4 lb. per cubic foot. Or the density of iron may be expressed as approximately 0.26 lb. per cubic inch.

Specific Gravity.—For many purposes, it is convenient to know the degree of density of substances compared with some particular substance which is taken as a standard. Water is the standard generally used for comparing the densities of solids and liquids, and air or hydrogen is the standard used in measuring the relative density of gases. Since the weight of a unit volume of a substance varies with the temperature and pressure, these factors are definitely fixed when the weight of the standard unit volume is obtained. Approximations are sufficient for all ordinary purposes, thus 62.4 lb. in place of 62.355 lb. is considered the weight of a cubic foot of water in all except accurate scientific work. If one divides the density of a substance, such as iron which is 449. lb. per cubic foot, by the density of water which is 62.4 lb. per cubic foot, one obtains the figure 7.2. This figure, 7.2, is called the specific gravity of iron with reference to water as a standard. It may be expressed as follows:

$$\text{Specific gravity of iron} = \frac{\text{density of iron}}{\text{density of water}}$$

$$\text{Specific gravity of iron} = \frac{449}{62.4} = 7.20$$

The specific gravity of any other substance may, of course, be obtained in the same manner. The *specific gravity* of a substance is the comparison or ratio of the weight of the body to the weight of an equal volume of a standard. This relation can be expressed by means of formulas in which

s is the specific gravity of a substance

W is the weight of the substance

K is the weight of an equal volume of a standard

Then:

$$s = \frac{W}{K}$$

$$K = \frac{W}{s}$$

$$W = K \times s$$

In some practical cases, the specific gravity of a solid can be determined by use of one of the laws of liquids. An object immersed in a liquid loses weight just equal to the weight of the displaced liquid. If the object is lighter than water, it floats just far enough out of water so that the weight of the water displaced equals the entire weight of the floating body. A floating substance, therefore, displaces its own weight of liquid. If the object sinks, it loses as much weight as the weight of the water displaced.

Hence, if a casting is weighed in air and then in water, the difference is the weight of an equal volume of water. This method saves us the necessity of finding the volume of the casting, since we need only to compare the weights of equal volumes without regard to what this volume is.

To illustrate: a casting weighs 22.8 lb. in air and 19.4 lb. in water. What is its specific gravity?

$$\text{Loss of weight of casting} = 22.8 - 19.4 = 3.4 \text{ lb.}$$

$$\text{Weight of equal volume of water} = 3.4 \text{ lb.}$$

$$\text{Specific gravity} = \frac{22.8}{3.4} = 6.7$$

If the substance is finely divided like sand, it can be put into a container of known weight and volume. There are containers especially made for this purpose. The container filled with sand is weighed. When the weight of the empty container is subtracted, the weight of sand is obtained. Since the volume of sand is known, the weight of an equal volume of water can be computed. Comparing the weights of equal volumes of sand and water, gives the specific gravity.

To illustrate: a vessel of 30-cu. in. capacity weighing $\frac{1}{2}$ lb. empty, weighs 2.233 lb. when filled with dry sand. What is the specific gravity of the sand?

$$\text{Weight of 30 cu. in. sand} = 2.233 - 0.5 = 1.733 \text{ lb.}$$

$$\text{Weight of 30 cu. in. water} = 30. \times 0.0361 = 1.083 \text{ lb.}$$

$$\text{Specific gravity of sand} = \frac{1.733}{1.083} = 1.6$$

*TABLE II.—SPECIFIC GRAVITY AND WEIGHTS OF A FEW SUBSTANCES

Substance	Specific gravity	Weight per cubic inch, in pounds	Weight per cubic foot, in pounds	Weight in pounds of other volume
Metals:				
Aluminum.....	2.56	0.0924	159.7	
Brass.....	8.60	0.3105	536.6	
to	8.20	0.2960	511.6	
Bronze.....	8.85	0.3195	552.2	
Calcium.....	1.57	0.0567	98.	
Chromium.....	6.50	0.2347	405.6	
Copper.....	8.82	0.3184	550.4	
Gold.....	19.32	0.6975	1,205.6	
Iron, cast.....	7.20	0.2600	449.2	
Iron, wrought.....	7.85	0.2834	489.8	
Lead.....	11.37	0.4105	709.5	
Magnesium.....	1.74	0.0628	108.6	
Manganese.....	7.42	0.2679	463.0	
Mercury.....	13.58	0.4902	847.4	
Nickel.....	8.80	0.3177	549.1	
Platinum, wire.....	21.04	0.7595	1,312.9	
Potassium.....	0.87	0.0314	54.3	
Silver.....	10.53	0.3802	657.1	
Sodium.....	0.98	0.0354	61.1	
Steel.....	7.80	0.2816	486.7	
Tin.....	7.29	0.2632	454.8	
Vanadium.....	5.50	0.1986	343.2	
Zinc, cast.....	6.86	0.2476	428.1	
Woods:				
Hickory.....	0.80	0.029	49.9	
Mahogany.....	0.90	0.032	56.2	
Maple.....	0.70	0.025	43.7	
Oak, white.....	0.80	0.029	49.9	
Pine, white.....	0.50	0.018	31.2	
Pine, yellow.....	0.65	0.023	40.6	
Spruce.....	0.45	0.016	28.1	
Walnut.....	0.65	0.023	40.6	
Liquids:				
Water.....	1.00	0.0361	62.355	
Water, sea.....	1.03			
Kerosene.....	0.80			
Linseed oil.....	0.94			
Muriatic acid.....	1.20			
Sulphuric acid.....	1.84			1 bushel,
Fuels:				
Charcoal.....	.....	.....	18.0 to 18.5	20
Charcoal, solidly packed.....	0.4	.....	25	
Coal, anthracite.....	.....	.....	55 to 65	67
Coal, anthracite solidly packed.....	1.5	.....	94	
Coal, bituminous.....	.....	.....	50 to 55	60
Coal, bituminous solidly packed.....	1.27	.....	79	
Coke.....	.....	.....	28	40
Other substances:				
Asbestos.....	2.8	.....	175	
Brick, common.....	1.8	.....	112	
Fire.....	2.3	.....	144	
Brickwork in mortar.....	1.6	.....	100	
cement.....	1.8	.....	112	
Cement, Portland.....	3.1	.....	194	
Concrete.....	2.2	.....	137	
Earth, loose.....	1.2	.....	75	
Rammed.....	1.6	.....	100	
Gravel.....	1.75	.....	109	
Limestone.....	2.6		163	
Sand, dry.....	1.6		100	
Wet.....	2.0		125	
Sandstone.....	2.3		144	
Sulphur.....	2.00		125	

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Problems

1. Determine the missing quantity:

<i>s</i>	<i>W</i>	<i>K</i>
3.25		25
7.13	482	
	48.7	62.5
	265	62.5

2. An iron casting contains $2\frac{1}{2}$ cu. ft. If its specific gravity is 7.21, what is its weight?

3. A cylindrical casting 4 in. in diameter and 9 in. long weighs 33.9 lb. What is its specific gravity?

4. (a) How many pounds heavier is a cubic foot of lead than a cubic foot of wrought iron? (b) Of iron than sand? (c) Of iron than aluminum? (d) Of brass than aluminum?

5. A steel casting displaces 4.84 gal. of water and weighs 302 lb. What is its specific gravity? (1 gal. water weighs approximately $8\frac{1}{3}$ lb.)

6. An irregular casting displaces 8 qt. of water. What is its specific gravity if it weighs 120 lb.?

7. A casting weighs 225 lb. in air and 192 lb. in water. What is its specific gravity?

8. A glass container of 15-cu. in. capacity weighing 0.8 lb. is filled with sand. The total weight is 1.7 lb. What is the specific gravity of the sand?

Topical Questions

1. (a) Assuming a deflated balloon with ballast to weigh 1,000 lb., what is the probable weight of the balloon and ballast when inflated or would there be any difference? (b) What has not changed? What has changed? Explain.

2. If iron bubbles or boils while being poured, gases are escaping through the iron rather than through the sand. Imperfect castings may result. How may information concerning density and specific gravity aid in preventing this?

3. If it were possible for one to survive and reach a point between the earth and sun where the gravitational pulls of the earth and of the sun are equal, what would be observed with reference to the weights of objects? (See pp. 1 to 6, "Common Science" by Carleton W. Washburne.)

4. How does gravitational pull affect the design of combustion chambers in furnaces and cupolas?

5. (a) What is the relation between ramming and venting of molds? (b) How may an understanding of density assist in developing skill in ramming and venting?

6. Compare the action of a ship in water with the action of a free cope of a mold into which molten iron is being poured.

7. (a) What are the relative densities of molding sand and cast iron?
(b) What application does this have in foundry work?

8. (a) From your experience, estimate the order of the specific gravities of the following substances: steel, brass, copper, aluminum, white pine, cherry, molding sand, and coke. (b) Then check your estimate by the table and find the reason for your errors, as for example, the fact that gold is much heavier than lead is often overlooked because it is used in smaller pieces.

9. Give an important reason for considering the relative specific gravity of sand and of iron in the use of gagers.

10. How may the understanding of specific gravity be used to aid in preventing or overcoming a number of the difficulties in molding practice?

11. Sulphuric acid and water mix in all proportions, and a large amount of heat is produced when very strong sulphuric acid is brought into contact with water. In making a mixture, why is the acid slowly poured in at the side of the vessel containing the water? Otherwise what might happen?

12. The composition of brass ranges from 10 per cent zinc, and 90 per cent copper to 50 per cent zinc and 50 per cent copper when the specific gravity ranges from 8.60 to 8.20. Explain the connection between composition and specific gravity.

13. Since wrought iron contains less silicon and carbon than cast iron, if you did not have the figures as to specific gravity of the metals, would you expect wrought iron to have a higher or lower specific gravity than cast iron? Explain.

Text References

1. HIGGINS, LOTHROP D., "Introductory Physics," pp. 17-26, 57-65.
2. SEARS, FREDERICK E., "Physics for Secondary Schools," pp. 26-41, 72, 647.

Reading Reference

WASHBURNE, CARLETON W., "Common Science," pp. 1-6.

CHAPTER X

INERTIA

In everyday experience, it has no doubt been noticed that considerable effort is required to set a heavy body in motion, even with every advantage of ball bearings, level roadway, etc. For example, an automobile weighing 1 to 2 tons requires considerable energy to move, even slowly, on a smooth and level pavement. A railway train on a level track, with all machinery in perfect condition and all possible power exerted by the locomotive, gains speed slowly at first and only gradually comes up to full speed.

Again, when the engineer desires to stop this same train, he finds that, with all brake power on, the train cannot be stopped under several hundred yards. In order to try this out on a small scale, one may

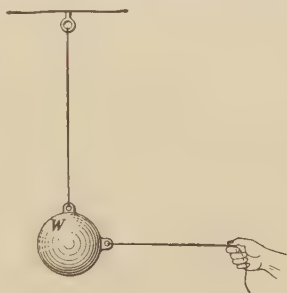


FIG. 4.

suspend a heavy weight, W , by a thin wire and move it by means of a cord. Friction is in this way reduced almost to zero, yet one finds that the weight resists the effort to swing it. In fact, if a sudden sharp pull is exerted, the cord may break without moving the weight to any great extent. Likewise, after getting the weight into motion, considerable force is required to stop it. This reluctance on the part of bodies to start or to stop is called *inertia*. Properly defined, inertia is that property of a body which makes it necessary to apply *force* to produce any change in the amount or direction of its motion.

Here are some examples of inertia: When a train or car stops too suddenly, one is thrown forward violently; persons have even been thrown through the windshield of a car.

This is because the passenger's body has a tendency to continue the motion it had acquired while the car was running. Since the passenger is not attached to the car, this tendency carries him forward when the car stops quickly. In a railway collision, the seats are often torn loose and thrown to the forward end of the coaches. In such a case, the inertia of the seats—that is, their tendency to continue their motion—is too great to be resisted by the fastenings. It is inertia which enables a soft lead bullet to penetrate a hard plank.

There are many applications of the principle of inertia, some simple and familiar to every one. When a carpet is beaten, the dust particles do not readily assume the motion of the carpet as it is struck aside by the beater. The particles, therefore, continue in the direction from which the blow came, are left behind, and fall to the ground or are blown away. When a hammer head is driven on its handle by striking the free end of the handle on some solid object, it is the inertia of the heavy head, reluctance to stop, which drives it farther and farther on the handle. It is inertia which enables the flywheel of an engine to steady the operation of the engine.

Topical Questions

1. Illustrate the operation of the force of inertia in the action of molten metal flowing around a core.
2. What can be done when the inertia of the core is deemed insufficient to resist the pressure of molten metal?
3. Why is it easier to shovel sand by swinging the shovel into the heap than by starting to swing the shovel at the point at which it enters the sand?
4. How may one use his understanding of inertia to decrease the strain in lifting?
5. (a) What practical differences must be taken into account in lifting a large pattern by the aid of a swinging crane, and in lifting a casting made from the pattern? (b) Explain the effect of inertia in these cases.
6. How does inertia contribute to loss in unnecessary stopping of machinery?
7. Mention different ways in which inertia is utilized in foundry operations.

Text References

1. HIGGINS, LOTHROP D., "Introductory Physics, pp. 27-28, 33, 69-71, 93-95.
2. SEARS, FREDERICK E., "Physics for Secondary Schools," pp. 215-217.

CHAPTER XI

ELASTICITY

If a rubber band is released after being stretched, it will snap to approximately its original length. If a piece of spring steel be released from pressure after it has been bent out of shape, it will return to approximately its original shape. Each of these materials possesses the property of elasticity which constantly tends to bring the rubber or the steel back to its original size and shape. Some materials, such as putty and clay, possess no elasticity at all.

Elasticity is that property of a body which causes it to recover, more or less perfectly, its original size and shape after the force which distorted it has been removed. An elastic substance, in the popular sense, is one which stretches or yields to a large extent as well as one which returns to its original size and shape. Scientifically, the property of elasticity refers only to the tendency to recover the original form and dimensions. Steel, ivory, and wood are in reality much more elastic than rubber.

If the distortion caused was in the form of the body and it recovers its form, as in the case of the rubber or the steel, the elasticity is sometimes referred to as *elasticity of shape or form*. If the distorting force caused merely a change of volume, as when a gas is compressed, the property is called *elasticity of volume*. Elasticity of shape or form is a property of solids only.

If one experiments with a steel spring, bending it repeatedly and applying each time a little more force, one finally bends it to a point at which it fails to return completely to its original form. Then the *elastic limit* of the material has been passed. It has not necessarily been weakened, but it will not return to its original shape without the assistance of external force. The change in shape due to exceeding its elastic limit is called a *permanent set*.

It must be understood that when force is applied to any material, that material changes its shape to some extent in every case. The force which is applied produces a stress in the material. A *stress* is the internal force that resists the change in the size or shape of a body acted on by external forces. It is measured in the same units as the force which produces it. The change of shape or size caused by the force is called a *strain*. Until the elastic limit is reached, the strain is exactly proportional to the stress; that is, if a certain strain is obtained by applying a stress of 100 lb., a stress of 200 lb. will produce exactly twice that strain.

In building machinery or constructing buildings, careful calculations are made so that the forces acting on various parts of the completed work do not reach the elastic limits of these parts and so damage the machine or structure. In fact, it is very seldom that machinery is designed in which the normal forces acting on any part amount to more than a fifth of the elastic limit.

Nowadays, most companies test carefully the materials used in their work. The most common tests are the *tensile* test and the *compression* test. In the tensile test, a carefully made specimen of the material is placed in a testing machine and pulled slowly. Careful record is made of the strain, which in this case is stretch or elongation, for various stresses; and the elastic limit is carefully determined. The strain may then be increased until the material gives way, thus indicating the breaking stress or *ultimate stress*.

Many materials cannot be tested in this way, either because they are not used under tension or because of the difficulty of making a proper specimen. These may be tested by compressing or squeezing them. The tensile test is most commonly used for metals and the compression test for stone, brick, etc. Both the elastic limit and the breaking stress or ultimate stress are usually determined. They are usually expressed as pounds per square inch. An ordinary grade of steel will stand a tensile stress of 60,000 to 80,000 lb. per square inch, but the elastic limit will not be much more than half this.

Cast iron has very little elasticity. Committee A-3 on Cast Iron of the American Society for Testing Materials in

"Standard Specifications for Gray Iron Castings," 1927, recommends that "the tension test shall not be made, for the reason that cast iron is almost devoid of elasticity and hence any deviation from an absolutely straight pull in commercial testing machines yields defective results."

Topical Questions

1. (a) What differences are observed in ramming molds in which thin patterns are used and in ramming molds in which thick patterns are used? (b) How is this related to elasticity?
2. (a) To what extent should a mold in which a thin pattern is used be peened? (b) How is this related to the elastic limit?
3. (a) Is a permanent set more easily developed in wood or metal? (b) To what extent do you believe this information should influence the choice of material to be used in making patterns?
4. Is it possible to bend any part of a flask during the pouring process? Explain.

Text References

1. SEARS, FREDERICK E., "Physics for Secondary Schools," pp. 188-191.
2. Standard Specifications for Gray Iron Castings, A 48-18, American Society for Testing Materials.

CHAPTER XII

FRICTION

The nature and effects of *friction* are so well known to every one that little explanation is needed. Friction is of two kinds, *sliding* and *rolling*. The resistance of *sliding friction* is felt when one slides a box across the floor. The resistance due to *rolling friction* is felt when one attempts to move a heavy car on a level road. A ball thrown through the air is resisted by air friction which is a variety of sliding friction. A boat moving on the river is retarded by the friction between the boat and the water—a sort of sliding friction.

Friction in bearings is a disadvantage in a machine; but there are some places where friction is not only an advantage, but a necessity. The brakes on an automobile, street car, or railway train are examples of the necessity of friction. In fact, friction is as necessary a force as any in nature. Without friction, one could not walk, nor drive an automobile. It would be impossible to pick anything up except by grasping it, for without friction the thumb and fingers could exert no lifting power.

There are some facts that have been learned about friction between smooth surfaces which should be remembered. These facts have been determined by careful experiment and are called the *laws of sliding friction*:

1. The resistance of friction is in direct proportion to the pressure between the surfaces in contact.
2. The frictional resistance does not depend upon the area of the surface in contact if the total pressure remains the same.
3. Friction is independent of the speed with which the surfaces slide.
4. Friction at starting is greater than friction after motion has been established.

It has also been found by experiment that friction between unlike materials is less than that between like materials. This is the reason brass, bronze, babbitt and wood are used as bearing material for steel or iron shafts.

Rolling friction is much less than sliding friction. This was discovered ages ago when men invented carts to transport loads, instead of dragging them on poles as some barbarous races still do. The wheel, in which rolling friction is substituted for much of the sliding friction, makes use of another mechanical principle which is not discussed in this chapter. Carts and wagons have been in use for many centuries, but in recent years rolling friction has been further substituted for sliding friction by the use of ball bearings and roller bearings. It is only within the past 45 or 50 years that it has been possible to produce hardened steel balls and rollers of sufficient accuracy in size for high speed bearings.

Friction is reduced, where it is undesirable, by lubrication. There are several classes of lubricants which are used either alone or in combination, but oils remain the chief lubricant in point of quantity used. Graphite and powdered mica are both used, sometimes alone, sometimes mixed with oil or grease. In the case of oil, the surfaces are separated by a film of the lubricant, and the friction is between the oil particles and the two surfaces instead of between the two surfaces. In the case of graphite and mica, the lubricating effect is partly due to the filling up of the small irregularities of the surfaces by the finer particles and partly to a substitution of rolling friction for sliding friction, the small particles of the lubricating material rolling between the two surfaces.

Topical Questions

1. Apply the first law of sliding friction to peening against the sides of a flask.
2. What uses are made of friction in the cleaning department of a foundry?
3. Describe the operation of a rattler or tumbling barrel with particular reference to the application of the laws of friction.
4. Explain the application of the second law of friction to the operation of emery wheels or other such power abrasives.
5. Explain increased heat resulting from increased speeds of emery wheels in view of the third law of friction.

6. Recalling the operation of inertia and also the laws of friction, state whether it would require more energy to operate an empty tumbler weighing 1,000 lb. or a partially filled tumbler of equal mechanical efficiency which weighs 1,000 lb.

7. Is the friction on the surface of a mold affected by the speed of pouring? Explain.

8. Suggest two ways by which the application of the laws of friction might lead to improvement in your department.

Text References

1. HIGGINS, LOTHROP D., "Introductory Physics," pp. 101-108, 155.
2. SEARS, FREDERICK E., "Physics for Secondary Schools," pp. 146-155, 181-186.

CHAPTER XIII

FRICTION AND EFFICIENCY

In the preceding chapter, it was learned that friction is in direct proportion to the pressure between the surfaces in contact, without regard to the area of these surfaces. This remains true as long as the pressure is not sufficient to crush or indent either surface. There are certain known limits for this pressure beyond which it is not advisable to go. Since the amount of friction depends upon the amount of pressure and not upon the area of the surface in contact, a smoothly finished steel block $2 \times 4 \times 8$ in. sliding on a smoothly finished surface will require a certain force to move it; and this force will be the same no matter on which side the block rests. This has been proved, by careful experiment, many times. The force required to move the block varies with the material of the slide, the material of the block, and with the condition of the surface, whether oiled or dry. Under the same set of conditions, the force will always be a certain percentage of the weight of the block. Thus, with a steel block sliding on an oiled bronze surface, the force required to move it will be only 0.05 or 0.06 of the weight of the block. The same block on a dry bronze surface will require a force equal to 0.15 or 0.20 of its weight. This decimal is called the *coefficient of friction*, and most hand-books give tables for the coefficients of friction with various combinations of substances.

The coefficients of friction for several combinations of materials are given below:

	Coefficients of Friction
Wood sliding on wood, not lubricated.....	0.20 to 0.55
Metal sliding on wood, not lubricated.....	0.20 to 0.60
Metal sliding on metal, not lubricated.....	0.15 to 0.25
Metal sliding on metal, continually well oiled.	0.05

In modern machinery, friction-loss may be reduced to a very low figure by the use of proper bearings and by proper care of them. Yet it is necessary to take friction into account in dealing with large installations, because power must be supplied to overcome that friction if the machinery is to work. In most plants, care is taken to see that the amount of power absorbed by friction is reduced to the lowest possible figure. It can readily be seen that if 100 horsepower (hp.) is being delivered by a motor to a reduction gear and only 60 hp. is being delivered to the machinery by the reduction gear, 40 hp. is being absorbed by friction or other sources of loss. The loss of efficiency from other causes than friction is an important subject but it is not considered in this lesson. Such a reduction gear is said to have an efficiency of 60:100 or $\frac{60}{100}$ or 60 per cent which would be very low. In such a case, the owner of the machinery would be losing the cost of 40 hp. constantly; and it would pay to replace the inefficient apparatus. It does not always pay to run machinery as long as it will hold together.

Efficiency must be the guide that determines whether or not it is economy to keep a machine or to scrap it. The *efficiency* of a machine may be defined as the ratio of the work accomplished by the machine to the energy delivered to it. In other words,

$$E = \frac{\text{work out}}{\text{work in}}$$

Topical Questions

1. Why should gagers always be placed upright against the sides or bars of flasks?
2. It is a well-known fact that molten metal avoids hard spots in the surfaces of molds. This is ordinarily explained by the fact that hard spots do not vent as readily as surfaces of less density. A question has been raised as to whether or not the hard spot offers frictional resistance equal to that of softer surfaces. What is your opinion of this matter?
3. When jolt ramming machines were first used, foundrymen were amazed to find that gases escaped much more readily than from hand-rammed molds; in fact, venting sometimes was found unnecessary. This is largely explained by the fact that hand-ramming produces very dense layers while jolted sand is densest directly next the pattern and decreases

in density toward the top of the flask. What, if any, application of the laws of friction may there be in this discovery?

4. What are the principal points of friction to be considered in connection with the operation of a blower?

5. How does friction of a fan belt affect the operation of a cupola?

6. What is the relationship between pattern drafting and friction?

7. If it requires 100 hp. to operate 20 molding machines in compressing sand, and each machine uses an average of 3 hp., what is the average efficiency?

References

See references in previous chapter.

CHAPTER XIV

MELTING POINTS OF METALS

The conversion of a solid into a liquid by the application of heat is termed *melting*. A further application of heat would in most cases result in the liquid becoming a vapor. This is called volatilization. This occurs occasionally in the case of certain metals, although the volatilized metal burns at the surface of the liquid in most instances.

It would be a mistake to think that the melting of a metal is a certain result of the application of sufficient heat. The use of borings from cast iron and steel is one of the difficult problems in the metal trades. Almost all other kinds of waste iron and steel can be readily remelted as scrap. The fine particles of iron and steel in the presence of sufficient oxygen in the cupola are apt to burn rather than melt. In the brass foundry, the melting flame is clearly distinguished from the oxidizing flame.

In the melting of metals, heat is absorbed in three different stages: the bringing of the metal up to the melting point, the melting operation, and the superheating of the molten metal. The extent of the superheating of the metal depends practically on the temperature at which the metal melts and, frequently, is an important question in the foundry. The amount of heat is measured in British thermal units (B.t.u.). A *British thermal unit* is the amount of heat required to raise one pound of water one degree Fahrenheit.

It must be emphasized that the heat required to melt a given weight of material does not depend entirely upon the melting point, although this is a factor. The specific heat has much to do with it. Thus, although copper melts at 1940° F. and aluminum at 1200° F., aluminum in coming to the melting point absorbs more heat because it has a specific heat of 0.214, whereas that of copper is 0.094.

The *specific heat* of a substance is the ratio of the heat necessary to raise the temperature of a certain weight of the substance one degree Fahrenheit to that required to raise the temperature of the same weight of water one degree. Aluminum (specific heat 0.214) absorbs about one-fifth as much heat as an equal weight of water absorbs during the same change in temperature; while an equal weight of copper (specific heat 0.094) requires less than half as much heat as aluminum or one-tenth as much as water does for the same change in temperature.

Assuming the temperature of a foundry to be 70° F., the number of heat units absorbed by a pound of copper in coming to the melting point is $1,870 \times 0.094 = 175$ B.t.u.; while a pound of aluminum requires $1,130 \times 0.214 = 242$ B.t.u.

Metals, like other substances, vary not only in the amount of heat required to make the same changes of temperature in given weights but also in the amount of heat absorbed during the melting process. The heat taken up by a substance during the change from solid to liquid form is not shown by the thermometer and so is termed "latent." A pound of ice at 32° F. absorbs about 144 B.t.u. in the change to water at the same temperature; and 144 is considered as the approximate *latent heat of fusion* of ice. The latent heat of fusion of copper is 75.6, and of aluminum 138.24.

To the 242 B.t.u. required to bring a pound of aluminum to its melting point, there must be added 138 B.t.u. in order to get the amount of heat necessary to melt a pound of aluminum, starting at ordinary room temperature.

The preliminary heating and melting of a pound of aluminum requires therefore approximately 380 B.t.u., and of a pound of copper 251 B.t.u.

These figures, 380 B.t.u. for melting a pound of aluminum and 251 B.t.u. for melting a pound of copper, seem to be in contradiction to certain items of experience. If a little melted aluminum is needed in an iron foundry, some aluminum is placed in an ordinary cast iron ladle without a lining of any refractory material. The ladle may then be placed on the core-room fire, and the aluminum is soon melted. Copper would not melt under these conditions.

The 740 degrees higher temperature required for melting copper than for melting aluminum is here a more important factor than the relative specific and latent heats of the two metals. Similarly, an amount of boiling water containing 400 B.t.u. would never melt even the smallest piece of aluminum.

As has been emphasized frequently, many factors enter into even apparently simple foundry operations. The melting points, specific heats, and heats of fusion are important but only a part of the melting process. We may estimate the amount of fuel needed to bring material to the proper temperature and condition for pouring. Many leakages of heat occur, and *such estimates must be corrected by experience and observation in each type of furnace.*

One of the factors in the heating and melting of metals is the speed with which heat is conducted or the *heat conductivity* of the metal being melted. Some materials like asbestos conduct heat very slowly, hence the use of asbestos gloves and asbestos linings in various places. The metals differ greatly in the rapidity with which they conduct heat. Silver, the best conductor, is taken as a standard and its conductivity is considered 100. On this scale the conductivity of aluminum is 48. cast iron 11.9 and tin 15.2. The quickness with which utensils of metal, especially of aluminum, get hot is well known. The relative heat conductivity of a number of metals is included in the melting data at the close of this lesson.

The size of the pieces into which metal is broken affects the rapidity with which heat is absorbed and melting proceeds. The smaller pieces have a greater extent of surface in proportion to weight than large pieces and, therefore, offer a better opportunity for the heat to penetrate.

Another factor in the cost of melting is the fuel efficiency of the particular furnace used. Furnace efficiencies range from about 70 per cent in the case of a blast furnace where the fuel and melting material are in contact, down to as low as 5 or 6 per cent in the case of furnaces such as the air furnace, in which the melting is done by a flame carried across the metal.

Because of these varying factors, which are unlike in almost every case of melting, *experience must be the final guide* to the

quantities of fuel required for foundry use in melting. Records kept by many foundries are available, and in most foundries the superintendent and foremen are guided in their estimates by such records.

A glance at the melting temperatures of metals suggests the need in the foundry for materials that can resist intense heat. These are called *refractories*. The subject of refractories enters into a number of foundry problems and must be considered from every possible angle. The melting temperatures of several kinds of brick are included in the table on melting data, in order to indicate the wide variation in the refractoriness of different materials.

Topical Questions

1. (a) What is the difference in the average melting points of steel and cast iron? (b) How does this affect the arrangement of steel scrap and pig iron on the coke in a cupola charge?

2. In order to get steel scrap, light gray iron scrap, and pig iron (solid pieces) to melt at approximately the same time, how should their layers be arranged on the coke bed in a cupola? Explain.

3. What common metals have the lowest melting points? What are some of the effects of this fact which you have observed?

4. Mention seven factors that may influence the cost per pound of melting metal.

Text References

1. MOLDENKE, RICHARD, "Principles of Iron Founding," pp. 95-103, 108-111.

2. SPRING, LAVERNE W., "Non-technical Chats on Iron and Steel," 2d. Ed., 1927, p. 83.

TABLE III.—MELTING DATA FOR SOME COMMON METALS

	*Specific heat	*Melting point degrees Fahrenheit	†Heat con- ductivity silver = 100
Aluminum.....	0.214	1200	48.
Antimony.....	0.051	1150	4.2
Bismuth.....	.....	500	1.8
Brass, average grade.....	.....	1700 to 1850	15. to 30.
Bronze, average grade.....	.....	1675	
Copper.....	0.094	1940	89.
Iron, cast.....	0.130	2300	11.9
Lead.....	0.031	620	8.2
Manganese.....	.....	2200	
Nickel.....	0.109	2600	14.
Silver.....	0.056	1740	100.
Steel.....	0.116	2500	6. to 14.
Tin.....	0.056	446	15.2
Zinc, cast.....	0.095	785	28.1
Silica brick.....	.....	3090 to 3100	
Bauxite brick.....	.....	2950 to 3245	
Fire brick, most common.....	.....	2830 to 3140	
Brick, chromite.....	.....	3720	
Brick, magnesia.....	.....	4950	

Low-grade fire brick is said to melt at 2560° F.

* Republished, by permission, from "Machinery's Handbook," copyright 1914, 1924, by The Industrial Press, New York, pp. 1245, 1175, 1277.

† Reprinted, by permission, from Kent's "Mechanical Engineers' Handbook," 10th Ed. p., 181.

CHAPTER XV

FLUIDITY AND LIFE OF MOLTEN METALS

The fluidity and melting points of various mixtures of molten metal are so closely associated in some foundry problems that they may easily be considered the same quality, but this would be a mistake. Both fluidity and melting point influence the life of metal.

Fluidity refers to the running quality of a substance. The more like water the substance is, the greater is the *fluidity*. The less easily a substance flows, the less its fluidity.

In the foundry, the longer time the metal remains fluid, the greater is the life of the metal. Fluidity and life of metal are not the same thing. *Fluidity* refers to a *quality* of the metal, and *life* refers to the *time* the metal retains this quality.

The *melting point* is the *temperature* at which a solid becomes liquid. This differs somewhat from the setting or freezing point which is the temperature at which a liquid changes to the solid form. In practice, the melting and setting points of metals may safely be considered the same.

Pure iron has a very high melting point and very low fluidity. A pasty substance with very low fluidity is formed when pure iron is heated, so pure iron can be wrought but not cast. The addition of various substances to iron lowers the melting point because different chemical compounds are formed. *Each metallic compound, element, and alloy has a fairly definite melting point.*

The melting point of an alloy may be lower than that of any of its constituents. Solder and a number of other alloys are of value in the industries because of their low melting points. An alloy is a new substance and not an average of the qualities of the others. This fact must be remembered when steel scrap is used in making iron castings. Water illustrates the fact that the qualities of a compound may be quite

different from the qualities of the elements of which it is composed. It will be remembered that the liquid, water (H_2O), is composed of two gases, oxygen and hydrogen.

Authorities differ as to the relative melting points of various gray and white cast irons. This is to be expected because each particular combination of elements in alloys has its own melting and setting points. The mixture is not as simple as that of alcohol and water used to prevent freezing of the water in the radiator of an automobile. In this case, a definite per cent of alcohol reduces the freezing point a certain number of degrees.

The fluidity, life, and melting or setting point of iron are greatly influenced by the presence of four elements in the alloy. One of these elements, silicon, exerts its influence indirectly through its power to throw carbon out of combination with iron. Carbon, oxygen, and phosphorus act directly through their compounds with iron.

Other factors, besides the composition of the charge, affect the fluidity and life of metal, so the practical man must know the *tendencies* of the various factors and control them to get the results he desires.

The more carbon that is combined with iron, the lower is the melting point of the alloy. This is a fundamental fact to keep in mind regarding the melting points of various alloys of iron. All the carbon in iron coming from the cupola is in a combined form, however much may separate out later as graphite.

The total amount of carbon affects the fluidity of iron only through its influence on the relative amount of graphitic and combined carbon. The fluidity of iron is influenced by the form in which the carbon is present. Combined carbon decreases the fluidity, while the formation of graphitic carbon tends to increase the fluidity and life. The reason for this action will be explained later in connection with the heat of solution.

Silicon affects the fluidity of iron through the carbon. Since the presence of combined carbon decreases the fluidity, and silicon tends to lower the proportion of carbon in the combined form, it follows that higher silicon, other conditions

being equal, means greater fluidity. It is a well-known fact that increasing the silicon in the charge lengthens the life of the iron.

The effect of oxygen in raising the setting point of iron is well known. Oxidation reduces the fluidity and takes away the life of the iron. The rapid setting of oxidized iron gives rise to many difficulties in the foundry.

Phosphorus is the element the foundryman frequently uses to increase the fluidity of iron. Except in large amount, phosphorus has no effect on the melting point, but even a slight increase improves the running quality of iron. High phosphorus increases the life of metal, other conditions being equal.

The fact that lowered melting point does not necessarily mean increased fluidity is shown by the effect of combined carbon. The more combined carbon, as has been said before, the easier it is to melt iron, but combined carbon definitely decreases its fluidity. Graphite has exactly the opposite *effect on fluidity*. To understand this action of graphite, *the heat of solution* must be considered.

When one substance goes into solution in another substance at the same temperature, there may be no change in temperature, or the temperature may be raised, or it may be lowered. For example, when sulphuric acid and water are mixed, the intense heat produced may cause an explosion unless care is used. On the contrary, when salt is added to ice, the solution absorbs heat and produces a temperature many degrees below that obtainable by ice alone. Thus, it is seen that heat may either be produced or absorbed when a substance goes into solution. Exactly the reverse takes place when the substance separates out of solution. The heat which is absorbed and cannot be measured is called *latent* or hidden *heat*. The heat which can be observed is called *sensible heat*.

The heat of solution accounts for some of the changes noted in the cooling of iron and the changes in fluidity. It is well known, both to practical men in the foundry and to scientists in the laboratory, that, under certain conditions during the process of cooling, a mass of metal may become hotter for a short time. Evidently, some of the latent heat

in the metal has become visible heat since there is no other source of heat available. This increase of heat during the setting of iron is due to some substance coming out of solution and giving up heat which on going into solution had absorbed heat.

When carbon goes into solution in molten iron, heat is rendered latent or hidden. During cooling, if some of the carbon separates out of solution as graphite, then this latent heat becomes visible heat. This prolongs the fluidity of the iron. Thus, according to Moldenke, "The higher the total carbon, the longer the period of fluidity in the case of high silicon irons." The silicon acts indirectly by throwing carbon out of combination, and as graphite is formed the heat of the mass is increased and the life prolonged.

The life of iron, or the time that it remains fluid, depends upon three factors:

1. The composition of the metal, especially as to phosphorus, silicon, and oxygen. These may influence the setting temperature as well as the time fluidity is retained.
2. The temperature of iron when poured. The more highly super-heated the metal is, the longer time required for it to cool down to its setting point.
3. Foundry practices that carry the heat away quickly or hold it in the metal.

These three factors cannot be considered separately in practice. A metal may have great fluidity because of its intense heat and yet not have much life. With such metal, foundrymen have been able to get excellent results which were formerly considered impossible. With greater heat, rapid handling and rapid pouring, they are able to get good castings with metal having short life. Formerly it was thought metal must have plenty of life to produce good castings. On the other hand, conditions on the molding floor may arise when the handling of the metal must be less rapid. Then it may be necessary to have high heat and a change in mixture giving longer life to the metal.

It is readily seen that a thorough understanding of these three factors would mean understanding all the chemical and physical changes that take place in the melting and cooling

of iron, a field in which research is being constantly carried on. While an effort is being made in research laboratories to learn more about these changes, that which is already known can prevent much of the scrap now produced in foundries.

Topical Questions

1. What is meant by iron "coming to nature?" How is the fluidity affected? Why? (Spring, p. 94.)

2. All conditions as to mixture and melting being the same, it becomes necessary to take more time in pouring. What two changes can be made to protect the quality of the castings? Explain briefly.

3. When a charge of iron is too thick, it is possible for one part of the heat to be much less fluid than another part of the *same* heat. Is the latter part of such a heat apt to be more fluid or less fluid than the first part? Why?

4. What is one reason that may account for a ladle of white-hot iron setting more quickly than a ladle of red-hot iron from another mixture? In this case, which may be hotter, the white molten iron or the red molten iron? (Moldenke, p. 106.) Explain briefly.

5. Under what general conditions may the temperature of one iron be higher than that of a second while its fluidity is lower? (Curry, p. 289.)

6. To what must particular attention be given in pouring if steel scrap is substituted for gray-iron scrap? Why?

7. Oxygen and combined carbon are alike in their influence in decreasing fluidity of molten iron. What is the influence of each on the melting point?

8. Make a table showing the influence of various elements on the melting point and fluidity of iron.

Text References

1. MOLDENKE, RICHARD, "Principles of Iron Founding," pp. 41-42, 95-108.

2. SPRING, LAVERNE W., "Non-technical Chats on Iron and Steel," 2d. Ed., 1927, pp. 4, 6-8, 83, 94, 142-144.

Reading Reference

CURRY, C., "Test Bars to Establish the Fluidity Qualities of Cast Iron," pp. 289-306, *Transactions of the American Foundrymen's Association*, Vol. XXXV, 1927.

CHAPTER XVI

HUMIDITY

Humidity is one of the phenomena the student of foundry practice should keep in mind as a possible means of improving the control of the cupola, although at present the relation is problematic. Every foundryman knows that a cupola runs very well on a heavy day, but the connection has never been established scientifically.

Air which is popularly described as "heavy" or "muggy" technically is said to be "humid." The barometer, an instrument for measuring the pressure of the atmosphere, proves what may seem difficult to believe: that the air which feels heavy and oppressive is in reality lighter than the air on a clear bright day. The reason for this is apparent when we learn to what humidity is due.

It is a matter of common knowledge that water exposed to the air will disappear by evaporation. It is also generally understood that this evaporation takes place more rapidly in a warm atmosphere and more and more slowly as the temperature drops. But it is equally important to know that even warm air can hold only a certain quantity of moisture per cubic foot at any given temperature. When air has absorbed water vapor to its maximum capacity for its temperature, it is said to be *saturated* and its relative humidity at that moment is 100 per cent. *Relative humidity* is the term used to denote the ratio of the amount of water vapor per cubic foot of air to the maximum amount of water vapor a cubic foot of air can hold at the same temperature.

Since air is able to hold only a certain amount of water vapor, you will understand that water may be protected from evaporation by a layer of saturated air. For this reason, water in any narrow mouthed vessel does not evaporate so rapidly as water left in an open vessel, such as a pan. In

the case of the pan, the saturated air is constantly being swept aside by air currents and fresh dry air brought into contact with the water; while in a bottle, even uncorked, the air becomes saturated and lies on the surface of the water protecting it from dry air which might absorb more vapor. Anything which will stop the movement of air over the surface will reduce evaporation. A cloth or tarpaulin over a heap of tempered sand will prevent its losing its moisture as fast as though it were exposed. Straw and leaves scattered over cultivated ground help to retain moisture by preventing the air from circulating freely in contact with the earth.

Normally, the air in buildings is too low in humidity, because when air is heated, as in winter, its capacity for moisture is doubled for approximately every 15° F. which it is raised in temperature, and few persons take the trouble to add moisture to the air. Various means may be employed to correct this, such as the use of evaporating pans of considerable surface. In industrial establishments, this is sometimes taken care of by automatic air conditioning apparatus. In time, it will doubtless be given the attention it deserves.

When the floor in the foundry is sprinkled, you have no doubt noticed the sudden relief from the summer heat. This is due to the absorption of heat from the air as the water evaporates from the floor and sand heaps. The humidity of the air seldom approaches saturation for long periods or over large areas. When the air is well loaded with water vapor and a drop in temperature occurs, it may fall below the temperature at which the amount of vapor it carries would produce saturation. If this occurs the air must get rid of some of its moisture. It does this by depositing it on cold surfaces with which it comes in contact, forming a dew, or on dust particles forming cloud or fog.

The deposit of dew on metal in the foundry is of interest to molders and furnacemen, since a bar of damp metal thrown into a ladle or pot may cause an explosion by the moisture laden metal being suddenly immersed in molten metal.

Ladle linings, too, are likely to "draw dampness" which is the common expression used in referring to the deposit of

water by moisture laden air. For this reason, as well as to avoid chilling the metal and cracking the lining, ladles should be well heated before pouring metal into them.

Topical Questions

1. What precaution should be taken before putting pieces of metal into a pot of melted brass, aluminum, or soft metal for the purpose of reducing temperature?

2. What is apt to occur if molten metal is poured into a cold ladle?

3. What special precaution is necessary when ladles have been relined? Why?

4. What is meant by preheating ladles? Is it always done? Explain.

5. If molten metal poured into a damp ladle may produce an explosion, why is it not dangerous to pour metal into green sand? Explain fully.

6. For what reasons is it desirable that the floor in a foundry be wetted down often in dry weather?

7. Explain how a cloth over sand or other moist material checks evaporation.

8. Explain how the evaporation from warm moist clothing may affect a person.

Text References

1. BRADBURY, ROBERT H., "A First Book in Chemistry," pp. 87-89.

2. HIGGINS, LOTHROP D., "Introductory Physics," pp. 175-179

3. SEARS, FREDERICK E., "Physics for Secondary Schools," pp 355-359.

PART III
OXIDATION, REDUCTION, AND
COMBUSTION

CHAPTER XVII

OXIDATION

If an inventory were taken of the immediate sources of all the energy on this earth, it would be found that the most extensive one of all is the combination of the atoms of a certain gas with each of two other elements. This combination takes place slowly in our bodies as long as life exists, and it takes place violently when a gas container explodes and wrecks a city. Technical control in the cupola aims to prevent the union of this active gas with iron, and to hasten its union with certain other elements.

Oxygen is this element. It will be recognized as one of the materials called "elements" because they had not been broken up into different substances. Quite recently, scientists have been learning how to break up the elements, but this process is so limited at present that for industrial purposes we may consider oxygen an element in the older sense.

Oxygen is so active chemically that two atoms join together to form a molecule of the same material rather than remain in one-atom molecules. Under certain conditions, such as those involving the passage of electricity, three atoms of oxygen may unite to form ozone. Fortunately for the world as we know it, oxygen is usually ready to leave a union with its own kind and enter into chemical combination with other elements.

The term *oxidation* has been stretched by chemists to cover many other reactions than the combination of oxygen with an element. This narrow definition of oxidation, the union of oxygen with another substance, will include, for the student of foundry technology, a large proportion of the chemical reactions he wishes to understand and control.

The technical name of the simple compounds with oxygen is *oxide*. Iron rust is one of the oxides of iron. Lead oxide is a dull-yellow powder containing lead and oxygen. When mag-

nesium is burned, or oxidized, a white powder, magnesium oxide, is produced. This is usually called magnesia. It should be realized that many compounds containing oxygen are not oxides, but all oxides are compounds of oxygen.

Several compounds in which oxygen occurs have already been mentioned—water (H_2O), and sulphuric acid (H_2SO_4). Two oxides of iron are quite different in some respects. Ordinary rust (Fe_2O_3) is the red oxide. It is so porous that air penetrates it and thus the rusting continues until the metal is deeply corroded or even entirely eaten through. The darker oxide (Fe_3O_4) can be produced on iron in such a way that a surface impervious to air is produced. Sheet iron thus treated is known in the trade as Russia iron, and was formerly a familiar material for stove pipe. The hematites (Fe_2O_3) both the red and the brown, are oxides of iron.

Oxygen is the active part of the mixture called the atmosphere. In fact, when one says he needs air to breathe, he means that he needs oxygen. Air being a mixture rather than a compound, the oxygen in it is readily available for union with any of the many elements for which it has a strong affinity.

Air contains approximately 23 per cent by weight or 21 per cent by volume of oxygen. This small weight of oxygen in a pound of air accounts for one of the wastes in the foundry which, at present, is considered largely unavoidable. In the melting process, more tons of air are used than the combined tonnage of coke and iron because each ton of air supplies only $\frac{23}{100}$ ton of oxygen, the active part of the air introduced into the cupola.

Since oxygen is an important part of the air about us, and is a constituent of water, of iron ores, and of many other compounds, it is not surprising to learn that oxygen constitutes about 45 per cent of the earth. As oxygen is both abundant and chemically active, we can expect oxidation to be a very common chemical reaction in daily life. It is, in fact, one of the most important processes, not only in daily living but in industrial activities.

In the oxidation of any substance, heat is produced. This heat may be produced so gradually that it is not noticed. The rusting of iron is an example of slow oxidation. Body

heat is a result of the oxidation of the food we have eaten. If there is not sufficient food to supply the heat and energy needs of the body, then the fat and other parts of the body may be burned.

A slow oxidation in certain oils produces a hard film on the surface where the oil is exposed to air. These oils are called "drying oils" or "driers" when added to paints and varnishes. Linseed is an example of such an oil used in the core room.

Remembering that all oxidation produces heat, it is easy to see what will happen when inflammable material, covered with a drying oil, is exposed to the air in a place where the heat from oxidation can accumulate. The loss from fires caused by carelessness or ignorance regarding this fact runs into many thousands of dollars annually and is entirely preventable.

If the heat from slow oxidation is confined, it may raise the substance to the ignition point. Then we have spontaneous combustion. Spontaneous combustion has been found, by investigators seeking to prevent the loss of coal in storage and on shipboard, to be a complex problem. It will be referred to again when combustion is discussed.

There are all degrees of rapidity in the process of oxidation. A violent explosion is the result of rapid oxidation involving expansion of gases, and a scarcely perceptible disintegration of a substance may result from this reaction when it is proceeding very slowly.

The slow union of oxygen with other substances is of as great importance as the rapid. It plays an immense part in activities of daily life, although no flame and no great temperature marks the process.

The purification of sewage is largely accomplished by the oxygen carried in the water. It is well known that fish soon die for lack of oxygen in water covered with oil which keeps out air. The slow oxidation within the body is the source of body heat. The action of driers in paints and core oils has been mentioned.

The slow oxidation of iron, as is well known, produces rust, but the exposure of iron to air or oxygen is not sufficient to produce rust. The difference in the damage from rust under dry and under moist conditions is well known. When

moisture is present under certain conditions, electrolysis takes place resulting in the production of iron oxide and other substances. Protection from moisture is as necessary in preventing the rusting of iron as is the protection from oxygen. The production of rustless steel has been the object of much research which finally has been successful. The problem was to find an alloy which does not oxidize.

The formation of iron rust is desired when castings are being cleaned in dilute sulphuric acid. The rust drops away from the castings carrying the sand with it thus leaving the metal clean. Here again use is made of moisture, for in strong acid the rust is formed much less readily.

It was mentioned at the beginning of this chapter that a large part of the energy in this world is derived from the union of one gas with either one of two other elements. This gas is oxygen and the process is oxidation. The two elements whose union, separately, with oxygen, heats cupolas and furnaces, warms living bodies, produces steam for engines, and purifies sewage are carbon and hydrogen.

Hydrogen is the lightest of known gases and occurs in combination in water, fuel oils, fats, sugars, the volatile part of coal, and many other substances. Carbon is a familiar element in several forms in plumbago, soot, and diamonds. In combination, it occurs in fuel oils, most iron alloys, and in practically all living substances, hence in wood, charcoal, coal, and coke.

The union of hydrogen with oxygen produces water (H_2O) whether this takes place in the combustion zone of the cupola, in the animal body, or living plant, or in the process of oxy-acetylene welding. The water thus produced may frequently be seen if the water vapor is condensed by a cold surface or cold air.

A very unstable compound is formed when hydrogen attempts to hold more oxygen in combination than is found in water. This compound is known as hydrogen peroxide (H_2O_2). It has some value as an antiseptic when it delivers oxygen hungry for a chemical union. When exposed to the air, hydrogen peroxide rapidly becomes hydrogen oxide, that is, ordinary water.

The two compounds that carbon forms with oxygen have a different relation to each other than the two compounds of hydrogen and oxygen. A slight change in the conditions of oxidation may result in the production of one when the other is desired. The wastefulness of this reaction, which takes place too frequently in many furnaces, will be considered under combustion. The danger to human life can best be understood from a glance at the chemical symbols and formulas.

An atom of carbon normally has a strong attraction for two atoms of oxygen as shown by the formula $C + O_2 = CO_2$. Carbon dioxide is the product. When there is insufficient oxygen to fully satisfy the carbon or when there is an excess of carbon, which is in reality the same proportion, all the carbon atoms share the available oxygen and all are only half satisfied. $C + O = CO$. The carbon monoxide thus produced is eager for more oxygen and will strive to take it from any source. The inhaling of a very little carbon monoxide literally robs the lungs of oxygen, producing a more violent effect than those gases which merely suffocate by cutting off the oxygen supply.

This characteristic of carbon monoxide accounts for many headaches and other unpleasant symptoms. It accounts also for the experience of a foundryman who found the men on the charging floor lying about the place unconscious.

Important as are the reactions of carbon and hydrogen with oxygen, the chemical affinities of oxygen include many of the metals. These will be considered in the next chapter.

Topical Questions

1. What is one advantage, depending upon oxidation, of helium over hydrogen in balloons?

2. (a) What is the most important drying oil used in the core room?
(b) What takes place in this oil which gives it its binding power?

3. Give an example of oxidation with no perceptible heat, which causes hundreds of thousands of dollars in waste each year.

4. How is this waste prevented? Explain this possible prevention from the standpoint of preventing oxidation.

5. What is one material used in iron foundries which contains oxygen in chemical combination but is not considered an oxide? Why? In what chemical group is it classed?

6. Give an example you have observed of the formation of water by the union of hydrogen and oxygen. How is this different from the sweating of a pitcher of cold water in a warm humid room?

7. (a) In the drying of linseed oil and its mixtures, which is the change taking place, physical or chemical? (b) How can the answer be proved?

8. Is there equal danger from spontaneous combustion from waste covered with various kinds of oil? If not, what oils are the greatest sources of danger? Why?

9. Suggest three precautions any one of which may be used with safety in the disposal or storage of oily waste or similar inflammable material. Explain each.

10. Why is the prevention of spontaneous combustion in coal a more difficult problem, practically, than the prevention of spontaneous combustion from oily materials?

11. What difference is to be expected in the heat produced in the formation of carbon monoxide and of carbon dioxide?

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CHAPTER XVIII

OXIDATION AND REDUCTION OF METALS

Losses in industry are frequently considered as a discredit to the persons responsible for them; usually they are accepted as a challenge by those in a position to change affairs. But there is one loss in foundry work that is accepted as a matter of course and its amount standardized. Only when this standard is exceeded do many foundrymen consider it urgent to search for the cause of this waste, which is known as "melting loss."

The melting loss in the cupola is the "reduction of the weight of metal incident to melting operation." The United States Bureau of Standards has advised that 5 per cent be figured as the standard for this loss, although their investigations showed a somewhat lower figure. Under some conditions in actual practice, this is kept as low as 3 per cent.

The melting loss is due in part to the oxidation of certain constituents in the charge. In the gray iron cupola, the elements oxidized are principally silicon and to a lesser extent manganese. Some of the iron may be oxidized with poor melting practice; but the result from this which commands the foundryman's attention is the serious damage to the qualities of the castings rather than the small loss of material.

Phosphorus is an element the amount of which neither decreases nor increases in the cupola. This is not because phosphorus does not oxidize, for phosphorus does readily burn to a compound with the formula P_2O_5 . It is the same old story of relative chemical attractions, and phosphorus remains in combination with iron in preference to forming an oxide.

Sulphur does not contribute to melting loss; although, as is well known, this element burns readily and at a comparatively low temperature. Sulphur has a strong affinity for

iron and occurs in most iron ores. At least a small amount remains in iron during its journey through the blast furnace. This results in almost all pig iron containing some sulphur. The coke brings in an additional quantity, and so the sulphur in cast iron tends to be higher than in the metal charged.

The foundryman tries to manage the cupola so that the iron is melted on the fuel at a point where there is least oxygen. Oxygen he must have, tons of it in fact, to burn the fuel rapidly enough to produce the temperature needed for melting. The air is supplied under pressure through the tuyeres which will be discussed later. The superheated metal drops down in molten form. Naturally, there is some contact between the oxygen and this metal, and a certain amount of oxidation is unavoidable.

The average loss of silicon is 10 per cent of the amount present. With high silicon iron and poor melting practice the melting loss of silicon may be as high as 0.30. So in calculating mixtures, provision is made for 25 more points of silicon than are required in the product.

The amount of manganese oxidized in the cupola is greatly influenced by the total amount present, but 15 per cent of the manganese is an average. Since manganese is present in such small amounts, this equals only about 0.1 per cent of the mixture.

The sand on the pig iron, the burnt sand on scrap, the oxidized iron in poor grades of scrap, and other losses bring the total average melting loss up to 5 per cent, although many foundrymen, especially with certain materials, keep it down much lower.

The one part of the charge that every foundryman hopes to keep entirely free from oxidation is the iron. The effect of oxidation upon iron is considered to be serious and far reaching, although there are many perplexities and differences of opinion on the subject. A number of difficulties arising from this source are described by Moldenke.

The degree of oxidation is influenced by the nature of the iron melted, the iron to coke ratio, the speed of melting, and the amount of air supplied.

An excess of air in the cupola which produces oxidized iron produces other troubles also, while insufficient oxygen pre-

vents trouble from oxidation of the metal but brings about difficulties such as cold iron and slow melting. The problem is to control the amount of air so as to have an adequate supply of oxygen to oxidize the fuel without the excess which will oxidize the metal.

The fluidity of iron is greatly decreased by the presence of even a small amount of iron oxide. This means greatly shortened life. The metal freezing in the gates and risers cuts off the supply needed to make up for the natural contraction during cooling. Shrinkage, as has been explained previously, is thus increased. In addition to all these other troubles, oxygen in the iron may produce blow holes which are revealed during machining.

The questions regarding oxidized iron can be better understood when the operation of the cupola is studied, for many closely interrelated changes take place during a heat.

Oxygen is involved in many of the chemical changes in the cupola. So far, only oxidation in which elements take oxygen *into* combination, has been discussed.

Frequently, one substance takes oxygen away from another, thereby reducing or deoxidizing it. The agency affecting this change is called a deoxidizer. Reduction has a broader application in chemistry than this reaction, but the narrow application is the only one to be considered at this time.

The reactions in which oxygen takes part may be summed up in a general statement. In *oxidation*, the substance oxidized becomes united with oxygen. In *reduction*, the substance reduced loses oxygen. When oxygen passes from combination with one substance into combination with another, the first substance is reduced and the second oxidized.

A number of the reactions in the cupola are explained in terms of oxidation and reduction. Certain elements are called "scavengers" because they rid the iron of the objectionable oxygen. Chemically speaking, these elements have a relatively stronger attraction for oxygen than has iron, so they are able to reduce the iron oxide to iron. This might all seem quite simple if it were not for the fact that it is not pure iron with which we are dealing, but a mixture of alloys and compounds which varies at different temperatures.

In some furnaces, the melting and combustion take place apart from each other, but in the cupola the iron melts on top of the fuel and so the processes are intimately associated. A consideration of combustion of fuel in the cupola must follow this survey of the oxidation and reduction of the constituents in the charge.

Topical Questions

1. Mention six bad effects of oxygen in iron and state the percentage of oxygen above which these effects may be produced (Moldenke, p. 55 to 58).
2. How might a specially long heat be expected to affect the percentage of sulphur in castings?
3. Mention four deoxidizers used in the iron foundry in order of their value. What are three of the factors that must be considered in selecting a deoxidizer?
4. What is the decimal equivalent of 25 points silicon? Give an example to illustrate this.

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CHAPTER XIX

COMBUSTION

Man has learned how to use to his advantage many forces, among which are wind, gravity, steam, electricity, and various rays of light and energy. Fire was one of the first great forces to be made a servant of primitive man, yet even today research is being carried on in industry in the attempt to control it more effectively. Heat treating is a subject of particular interest in the foundry.

Mention has been made of the pyrometer, an instrument that measures the degree of the intense heat in furnaces, and of the British thermal unit used in measuring the amount of heat. There are several important sources of heat in the foundry: the combustion of fuels such as coke and fuel oil, and electricity, which is used extensively in the melting of steel. The combustion of fuels will be taken up at this time.

Combustion in a broad sense includes any chemical combination that produces light and heat. Iron in a finely divided state and sulphur unite at high temperatures with great violence, producing heat and light. This is combustion in the broad but not in the usual sense. In popular language, combustion refers to the process of oxidation when it is sufficiently rapid to produce heat and light or burning. This definition is not quite accurate enough for the present purpose since hydrogen, one of the two most important constituents of fuels, burns with an almost invisible flame, or practically no light. It is better to think of combustion as producing heat and, usually, light.

Flame is burning gas. Not all solids change to gas before they are oxidized. Iron, for example, burns in the solid state, the glowing solid particles accounting for the sparks observed when iron filings or other small particles of iron are burned. A substance that volatilizes just before oxidation may produce glowing particles which give color to the flame. Candles and

ordinary illuminating gas owe their luminosity to particles of carbon which are heated so hot that they glow. Lamp black, which is nearly pure carbon, collects on a cold refractory material held in a gas flame and thus indicates the presence of free carbon in the flame.

"Kindling temperature" is a term that was used before a number of the factors entering into combustion were known. This temperature was supposed to be a fairly definite one at which each combustible substance took fire or ignited.

It is true that the vapors from naphtha burn at a lower temperature than gasoline, and that crude oil must be raised to a still higher temperature than gasoline before it will volatilize and burn. Other factors enter in, however, such as the concentration of the vapor. *Kindling conditions* are the conditions including temperature under which a particular substance begins to burn. Some conditions other than temperature may account for the explosions, the causes of which at present seem mysterious.

The total *heat* that can possibly be obtained from the combustion of any fuel depends on the amount of the combustible elements in the fuel. The most important elements in most fuels are carbon and hydrogen, though the Bessemer converter depends for its heat upon the oxidation of silicon and manganese as well as carbon. Sulphur, too, yields heat when burned, though the objectionableness of its products of combustion makes its presence undesired in fuels.

The heat produced in the burning of several elements is given in Table IV.

The burning of 1 lb. of carbon produces 14,600 B.t.u. and 1 lb. of hydrogen produces 62,000 B.t.u. This at once explains why fuel oils rich in hydrogen are used in the production of great heat.

The heat usually available from a fuel depends upon several factors in addition to the composition of the fuel as to elements. For this reason, the analyses of coke and coal do not specify the content of carbon and hydrogen but rather the amount of other constituents (containing carbon and hydrogen) which directly affect the fuel value. A fuel analysis usually specifies the per cent of fixed carbon, of volatile matter and of ash.

TABLE IV.¹—HEAT VALUE OF ELEMENTS

Elements	Product of combustion	B.t.u. per pound
Carbon.....	CO	4,450
Carbon.....	CO ₂	14,600
Hydrogen...	H ₂ O	62,000
Silicon.....	SiO ₂	11,450
Phosphorus..	P ₂ O ₅	10,600
Manganese...	MnO	2,975
Iron.....	FeO	2,110
Sulphur.....	SO ₂	4,050

¹ Reprinted by permission, from the 10th Ed. of Kent's "Mechanical Engineers' Handbook," p. 858; and Moldenke's "Principles of Iron Founding," p. 325.

The fixed carbon burns where the coal or coke is placed. The glowing fuel bed is composed of fixed carbon. The volatile matter is driven out of solid fuel by high heat and it burns or escapes. The proportion of volatile matter burned depends upon the construction and the operation of the furnace or cupola. Practically all of a liquid fuel is volatile matter.

Variations in composition and heating value of fuels are shown below:

TABLE V.¹—COMPOSITION AND HEATING VALUE OF A FEW FUELS

Fuels	Fixed carbon, per cent	Volatile matter, per cent	Heating value per pound of combustible, B.t.u.
Anthracite.....	97 to 90	3 to 10	14,800 to 15,400
Semi-anthracite.....	90 to 85	10 to 15	15,400 to 15,500
Semi-bituminous.....	85 to 70	15 to 30	15,400 to 16,000
Bituminous, Eastern.....	70 to 55	30 to 45	14,800 to 15,600
Bituminous, Western.....	65 to 50	35 to 50	12,500 to 14,800
Lignite.....	under 50	over 50	11,000 to 13,500

¹ Reprinted, by permission, from the 10th Ed. of Kent's "Mechanical Engineers' Handbook," p. 861.

The composition of coke is what would be expected from the process of its manufacture. The most common kinds are

the product of the dry distillation of bituminous coal. The larger part of the gases is driven off furnishing an excellent fuel. This reduces the volatile matter and proportionally increases the fixed carbon and ash. Limits suggested for the composition of coke are:

	Per Cent
Volatile matter, not over.....	2
Fixed carbon, not under.....	86
Ash, not over.....	12
Sulphur, not over.....	1

Another factor which frequently enters into the amount of heat derived from the combustion of a solid fuel is the completeness of the burning of the carbon.

Carbon, as has been mentioned previously, may burn to CO or CO₂, depending upon whether there is limited or abundant oxygen available. The difference in heat produced is very great as was shown in a preceding table. When carbon monoxide is formed, 4,450 B.t.u. per pound of carbon are produced. When carbon dioxide is formed, 14,600 B.t.u. per pound of carbon are produced. If carbon monoxide is the final product produced in the oxidation of the carbon in cupola fuel, the wastefulness of this partial combustion is obvious. The waste for every pound of carbon burned will be the difference between the possible 14,600 B.t.u. and the actual 4,450 B.t.u. produced or at least 10,000 B.t.u.

The danger to human beings from CO escaping from the furnace or cupola has been referred to. One more trouble may come from this gas in the operation of the cupola.

Carbon monoxide is usually formed as a natural part of the process of burning solid fuel. This occurs in the interior of the mass of fuel where the carbon is in relatively large proportion. Under good control, this partially burned gas, together with the volatile matter, is brought in contact with more oxygen under such conditions that it burns where heat is desired. Sometimes, in a cupola, these gases rise above the usual combustion zone before they take fire. In this case, the foundryman has the troublesome and wasteful situation of the stack being on fire.

The expression "incomplete combustion" is used in two different senses. A fuel is popularly said to be incompletely burned when a part of it falls through the grate or goes up the chimney without having been consumed. The incomplete combustion of carbon, in a scientific sense, means a union of carbon with only one-half the amount of oxygen with which carbon is capable of uniting. This is the sense in which incomplete combustion is used when the waste from carbon monoxide is being considered.

The combustion of carbon may be complete in the cupola and yet the operation be conducted uneconomically. A very simple fact regarding combustion is sometimes overlooked in the foundry and this oversight causes serious losses. It would seem to be obvious that the heat of combustion is produced where the combustion takes place, and the most heat is produced where the most combustion (of the same elements) is occurring. Let this point be fixed in mind before noting how its application may be overlooked.

The boiling of Bessemer steel in the converter is due to the combustion of the silicon, carbon, and manganese within the molten bath, the heat thus being produced throughout the entire mass. In the cupola the melting zone is just above the tuyeres. After the iron has dropped down through this zone, there is no opportunity to add more heat to it.

The fact frequently overlooked is that no heat is added to iron after it is melted, so naturally the foundryman must melt at the temperature desired. Where large castings are to be poured, and great fluidity is not needed, there is sometimes a tendency to save coke. If the fuel supply is too limited, the melted iron may not be hot enough to drive off the slag and gases. The iron may be hot enough to pour the large castings, but their quality may be injured by the impurities held in the cool iron, cool here meaning some degrees under 2300° F.

A cupola operating with hot blast instead of cold blast has been sought as a means of improving the efficiency of combustion in the cupola. The comparatively low efficiency of cupolas is due principally to the incomplete combustion of a portion of the carbon and to the loss of sensible heat in the gases leaving the stack.

The use of the stack gases for preheating the air supply is an established practice in the blast furnace and in the openhearth furnace. There have been difficulties with the preheating of the air in the case of the air furnace and the cupola, the overcoming of which has been the object of much experimentation. It is claimed, by the manufacturers of the Griffin Hot Blast Cupola, that the thermal efficiency of the cupola is increased from 30 to approximately 50 per cent in their cupola by the securing of more perfect combustion, and the decreased loss of sensible heat in the escaping gases.

Spontaneous combustion of fuels presents more difficult problems than the spontaneous combustion of inflammable materials covered with dry oils. Difficulty from the latter is usually traced to carelessness, but coal must be stored and transported in large quantities, and even with the best of care some kinds may begin to heat. Not all kinds of coal heat and are subject to spontaneous combustion, but the danger is widespread enough that the subject has been and still is being investigated.

One result of these investigations has shown that the very precautions taken to prevent fire in masses of coal may, under certain conditions, favor combustion. Thus, the pipes put into piles of coal to carry away the heat may supply oxygen needed to produce more heat or they may provide ventilation that carries away heat as it is produced. Moistening coal is said to decrease danger of fire because the vaporizing of the water cools the mass and, also, because the water keeps out oxygen. Yet, the objection to moist coal as a fire hazard was, formerly, almost universal in popular belief, and was registered in legislation against wet coal being placed on ships.

There is agreement on a few points regarding spontaneous combustion of coal. Not all kinds of coal are subject to this fire hazard, some kinds of soft coal being the most dangerous. This coal breathes or absorbs oxygen producing heat which may accumulate to the danger point. The hunger of coal for oxygen is largely satisfied within the first few months after the surfaces of pieces have been exposed. The pre-

vention of spontaneous combustion of coal involves the control of many factors so that the heat produced will be dissipated rapidly enough to prevent accumulation with consequent rise of temperature.

Combustion has been discussed, so far, entirely from the standpoint of fuels. The combustion process is of importance in the foundry, also, in connection with the bonding of sand and with cores. The value of certain bonds, and other constituents of molding sands and cores, is due to their reaction under the high heat of the molten metal.

It is well-known that the burning of sawdust in cores protects the weak hot brass from strains. Steel is poured at a temperature of 2850 to 3100° F. and iron at 2300 to 2900° F. All of these temperatures are high enough to burn some of the constituents of molding sand and cores. Other parts may be volatilized without being burned. Remembering that hydrogen burns to H_2O and that steam requires about sixteen hundred times as much space as the same weight of water, it is easy to see the practical need for providing a means of escape for this gas, and the others that are formed during pouring. Venting is for this purpose.

The gas produced during pouring may be due either to volatilization or to combustion or, as is more common, to both processes. A recent report on materials used as binders in foundry core sands gives percentages regarding this characteristic. Combined volatile and combustible matter constitute 95 per cent of both linseed oil and rosin. Fire clay is described as 5 to 10 per cent volatile due to the water held in combination and it is also classified as incombustible.

Topical Questions

1. If very thin copper foil is introduced into a glass tube containing pure chlorine gas, the copper immediately combines with the chlorine producing light and heat. Is this combustion? Explain.
2. What points are important in deciding which to use, coal or oil, for a given purpose?
3. What would be the results if a too small volume of air were used in the cupola? What if a too large volume were used?
4. Explain the two different meanings of incomplete combustion and give examples of the occurrence of each. Which is more largely physical? Chemical?

5. (a) Explain the loss of efficiency after long use of the carbon filament lights. (b) Does this occur with tungsten bulbs? Why? (Consult unabridged dictionary for tungsten if necessary.)

6. Define (a) smoke, (b) incandescence, (c) volatile substance, (d) spontaneous combustion. (e) Give an example of (b), (c), and (d) not mentioned in this chapter.

7. (a) Mention three fuels used in cupolas and different kinds of furnaces, and compare them as to content of carbon and hydrogen. (b) Compare them also as to content of volatile matter and fixed carbon. Make comparison by means of figures only.

8. (a) What is meant by the volatile matter in a solid fuel? (b) In which is the percentage of volatile matter higher, hard or soft coal?

9. (a) What effect does this difference in percentage of volatile matter produce on the source of possible waste in burning these fuels? (b) What solid fuel you have used either in the foundry or at home has the highest percentage of volatile matter? The lowest?

10. (a) What arrangement of materials in the cupola leads to the production of carbon monoxide no matter how much air is supplied? (Moldenke p. 207; last paragraph 255; pp. 318; 327.) (b) Trace briefly the possible formation of carbon dioxide and carbon monoxide from the first place in a cupola where combustion takes place on through the stack, including the space both below and above the charging door.

11. (a) In practice, what is a satisfactory proportion of the carbon dioxide and carbon monoxide in the cupola stack? What is considered poor practice? (b) What condition of coke on the bed produces a high percentage of carbon monoxide?

12. Which is hotter, the yellow or the blue portion of an ordinary flame? Why?

13. How can a yellow flame in a fuel burner be changed to blue? When should this be done?

14. Why must the foundryman melt iron as hot as he wants to use it? That is, why is no heat added to iron in the cupola after it is melted?

Foundry Problems

A foundryman who was producing heavy castings began to have much trouble from gas holes. He had just begun using a new consignment of pig iron and thought this was the source of the trouble. The expert who was called in advised another bushel of coke in each charge, and the trouble was at once overcome.

1. Trace the effect of the additional coke through to the lowering of the scrap and explain.

2. Why had the foundryman been able to pour, successfully, the iron as cold as it must have been before the coke in the charge was increased?

3. What probably led the expert to suspect the lack of fuel rather than the new pig iron as the source of trouble?

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CHAPTER XX

EFFECTS OF PRODUCTS OF COMBUSTION UPON ANIMAL LIFE

We have already learned that the heat of animal bodies, without which there is no life, is the result of a slow combination of the oxygen we breathe with the hydrogen and carbon in our bodies. This union is taking place constantly in every living cell of the body, though at different rates.

The waste products of this slow combustion are thrown off by the kidneys, the sweat glands, and the lungs. The principal waste products from oxidation within the body are the same as are produced in the burning of fuel. These are principally water, from the oxidation of hydrogen (H_2O), carbon dioxide (CO_2), and carbon monoxide (CO).

As in combustion in furnaces, the carbon dioxide produced in the body is the result of complete combustion of carbon and the monoxide is the result of insufficient oxygen for the carbon. Carbon monoxide is produced in very small quantities in the living body for, fortunately, the combustion here is usually carried on much more efficiently than in some cupolas. There are small quantities of other products produced by oxidation in animal bodies, but these are here considered only as a whole.

If one is confined in a small, air-tight space, the accumulation of waste products soon renders the air unfit to breathe. There is much to be learned on this subject. Surely water vapor, increasing the humidity, cannot be the cause of the fatal results of suffocation in an enclosed space. It has been proved that an animal can breathe comfortably in an atmosphere containing many times as much pure carbon dioxide as the amount of carbon dioxide from his own breath in a place where he would perish from suffocation. Evidently the small amounts of other products of combustion in connection with the carbon dioxide are unfavorable to life.

In order to understand the difference between suffocation and poisoning from the products of combustion, the frequently mentioned qualities and effects of the two compounds of carbon and oxygen may be compared.

Carbon dioxide is a heavy gas and is mainly eliminated by the body through the lungs. It is by far the most abundant carbon waste product in the gases of furnaces and cupolas even with efficient operation. It is not to be regarded as a poison. It will produce death, if present in sufficient quantity, merely by shutting off the supply of free oxygen. This may be compared to drowning by water. The water, also, is non-poisonous, but it shuts out the oxygen supply.

If sufficient carbon dioxide from the combustion of fuels is present to cause injury it will be apparent to the experienced by its effect on the eyes, for while the gas is *odorless, tasteless, and colorless*, it combines readily with water and forms carbonic acid, H_2CO_3 . So, when this gas forms a considerable percentage of the air, sufficient may be absorbed by the moist surface of the eyeball to cause irritation and smarting. This is not an infallible sign, because some seem not to be affected.

Very different from carbon dioxide or water vapor is carbon monoxide. This gas is exceedingly poisonous and when the quantity present in the air reaches only a very small percentage, it is fatal to life. Carbon monoxide is apt to be formed in coke or charcoal fires, especially in furnaces such as the cupola, where the products of combustion pass through a mass of broken red or white hot coke on their way up the stack. Salamanders also produce a certain amount of CO, but it is so thoroughly diluted by fresh air as to be harmless in most cases. Nearly all combustion of carbon produces some CO. It is only when the products of combustion are poured out into a closed space that the amount of this deadly gas can accumulate to a fatal percentage.

Carbon monoxide is a real menace, however, for it is colorless, odorless, tasteless, and without any irritating effect whatsoever. A quantity as small as 1 part in 100,000 parts of air is harmful and a percentage as low as one-eighth of one per cent will produce death.

One of the harmful effects of inhaling tobacco smoke is due to the effect of carbon monoxide produced by the incomplete combustion in the pipe or cigarette.

It is fortunate that carbon monoxide, the most dangerous of the gases produced in combustion, is slightly lighter than air and, therefore, soon rises from the floor in a closed place. If it were heavier than air like its cousin, carbon dioxide, fatalities would probably be more common even than they are. These fatalities are usually in private homes or garages where often too little attention is given to ventilation. All progressive concerns give this vital need the attention it deserves.

Deaths from carbon monoxide poisoning have been increasing in number the past few years because of the larger use of heaters and fuels under conditions favoring incomplete combustion of carbon and accumulation of the waste products where human beings are working. This is entirely preventable, and an insurance company is sponsoring a campaign of education aimed to decrease suffering and loss from this cause.

Certain other gases formed by the combustion of impurities in fuels are harmful. Coal is apt to contain streaks of iron pyrites or, as it is known to the chemist, iron disulphide (FeS_2). This may be seen in nearly any coal pile. It is a brassy colored, crystalline substance and is usually found in thin layers or streaks. It burns with the coal forming an iron oxide (Fe_2O_3) and sulphur dioxide (SO_2). This sulphur dioxide is very irritating to the membranes of the nose, throat, and lungs. It is a cause of discomfort from the use of salamanders.

A quantity of sulphur dioxide, sufficient to cause injury, will advertise itself by its irritating effect on the lungs and the asthmatic feeling in the bronchial tubes which results from the attempt to expel an irritating substance.

There is just one method of combating the dangers due to the presence of some of the products of combustion in the air—that is, constant care and a constant supply of fresh air. Where open fires are used, these destructive gases will be present. In such cases, enough fresh air must be introduced to dilute the waste products to a point where they are not a menace.

The modern foundry is heated, not by salamanders except in emergency, but by warmed air discharged from pipes at

many points thus producing a uniform bearable temperature. In such foundries, there is no risk from poisonous gases. Wherever the open fire is used, care must be exercised or the workers risk headaches and other illnesses, or even death.

Topical Questions

1. Knowing that carbon monoxide is lighter than air, how may salamanders be rendered reasonably safe?
2. The soft metal or babbit furnaces are sometimes heated by gas without stack connections. Is this safe? If fairly safe, is it conducive to health?
3. Metals as well as fuels are sometimes burned in considerable quantities during melting. Name two such metals and state whether the products of such combustion are harmful to life.
4. Is there usually danger from furnace fumes in the foundry? Why?
5. Mention one or two common types of furnace that require some kind of metal hood to carry away products of combustion.
6. From your own experience, describe a case of injury from the products of combustion, and state how it could have been prevented.

Reading Reference

1. SMITH's "Intermediate Chemistry," revised and rewritten, JAMES KENDALL and EDWIN E. SLOSSON, 1923, pp. 333-340.

PART IV
FORCE AND MOTION

CHAPTER XXI

FORCE

In every phase of modern life the application of force to some human requirement is encountered. On every hand, in nature is seen the operation of great forces. The fall of bodies to the earth, the flow of streams, the rush of storms, the growth of plants, the movements of animals; all these are brought about through the agency of force. If examined carefully, it is seen that every change in the material world is effected in this way.

From the foregoing observations, one arrives at the only definition of force which has ever been given: *Force* is that which produces, or tends to produce, motion or change in motion. Of the real nature of force, nothing is known; only its effects can be seen and defined.

In everyday work in the foundry, one may observe a multitude of ways in which force is applied to the needs of the business. The lifting and handling of flasks, cores, core boxes, and castings; the lifting and pouring of molten metal; the moving of material over transfer tracks and its transportation up and down the foundry by means of cranes; the operation of molding machines, air rammers, and chipping tools; and even the ramming, shoveling, and other operations performed by hand—all are examples of the application of force.

Forces are measured by comparing them with the gravitational pull of the earth on some standard mass, such as the pound mass. In a previous chapter, it was learned that weight is the measured attraction of the earth for material bodies. A weight of 10 lb. will deflect the indicator of a spring balance to a certain mark. Any other force which will deflect the indicator of the spring balance to the same point is said to be a force of 10 lb.

If a core is lifted from the ground by a hand hoist, it may be held suspended by a force just equal to its weight. It is said to be in equilibrium or balance. Should the lifting force exceed the weight of the core by even a little, the core will rise. Should the lifting force diminish by a little, the core will slowly sink toward the earth. In the one case, there is an unbalanced lifting force; in the other, a part of the weight is unbalanced by any lifting force.

The visible effect of the application of force is motion. Several forces may act at one time upon the same object and each will produce its effect independently of the others.

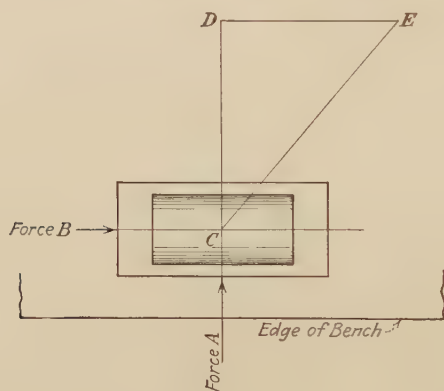


FIG. 5.

Thus, a flask may be lifted from the floor by a crane and, while rising from the ground, may be moved down the aisle by the force which drives the crane and across the aisle by that which moves the trolley. Three forces, each producing an independent effect, have acted upon the flask. Had the flask been acted upon by each of the three in succession instead of all together, it would have reached the same destination, but by a different path through the air.

In Fig. 5, is shown the plan of a core box resting on a smooth bench. A force, *A*, may be applied to move the core box from *C* to *D*. Afterwards another force, *B*, may be applied which moves it from *D* to *E*. It has been determined by experiment that if both forces act together, the core box

will move along the diagonal from C to E . Thus, if the relative amount of two forces, which are applied at the same time to a load, is known, the direction in which the load will move can be determined.

CD and DE have been drawn so that their lengths are proportional, respectively, to the forces A and B , and so that their directions are parallel to their respective lines of action. If the core box is free to slide along the bench and if force A amounts to 10 lb. and force B to 15 lb., the amount and direction of the actual force resulting from the two may be determined as follows:

1. Draw CD parallel to AC and proportional to force A on any scale.

2. Draw DE parallel to BC and proportional to force B on same scale.

3. Draw CE . Then CE will be proportional to the resultant of AC and BC on the same scale as DC and DE .

A *resultant* of two or more forces is a single force which, acting alone, would have the same effect as to distance and direction, as if the other forces had each acted independently on an object.

In the case of double slings this same problem is presented. If a load is supported by a double sling as in Fig. 6, it is important that one know the real force acting on each chain or rope in order that he may be sure the load is not too heavy for the sling.

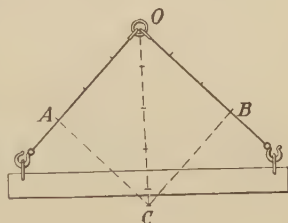


FIG. 6.

Let it be assumed that each chain is good for a straight pull of 3 tons. Lay off along the line of each chain a distance proportional to the safe load on that chain, using any convenient scale. In this example, we may let $\frac{1}{2}$ in. represent 1 ton. These distances will be OA and OB . From A draw AC parallel to OB and from B draw BC parallel to OA . Draw the diagonal OC . The length of OC represents the safe load on the double sling to the same scale as OA and OB . In this case, measurement may show OC to be $2\frac{3}{16}$ in. long, which at $\frac{1}{2}$ in. to the ton represents $4\frac{3}{8}$ tons, the safe load on the double sling.

Problems

In solving these problems, reference may be made to lessons in mathematics on Diagrams and Curves.

1. Find the safe load on a double sling of $\frac{1}{2}$ -in. plough-steel cable when the two cables are spread at an angle of 45° ; 60° ; 90° . Determine by diagram.

2. Using loads up to 6 tons as abscissas and angles from 0 to 180° as ordinates plot a curve showing the relation of safe load to angle on double slings of 1-in. plough-steel cable. Diagrams for 0° , 30° , 60° , 90° , 120° , 150° , and 180° are suggested. See Fig. 8. What are the results at 0° and 180° ? Can a double sling actually be put in use at 180° ? Explain the answer. Refer to Figs. 6 and 7 for this problem.

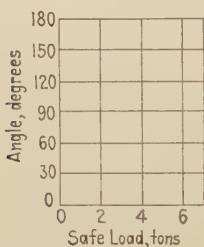


FIG. 7.

FIG. 8.—Safe load on 1" double sling in tons.

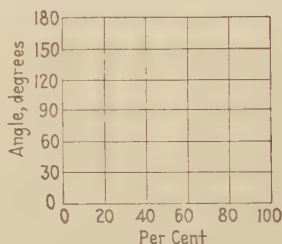


FIG. 9.—Percentage of full strength of both cables or chains of double sling used at various angles.

3. From data figured for Problem 2, using percentages from 0 to 100 as abscissas and angles as in Problem 2, plot a curve showing the relation between the percentage of the full strength of both ropes or chains, and the angle at which they are spread. This curve is true for any size of rope. See Fig. 9.

Topical Questions

1. Through what agency is force applied to operate cranes?
2. Is there any difference between a force of 20 lb. exerted by an electric motor and a force of 20 lb. exerted by a compressed-air motor? Explain.
3. Flasks either are clamped together or they are heavily weighted. Why is this done?
4. What force may cause the sand in the cope to be pushed upward between the bars?

Text References

1. HIGGINS, LOTHROP D., "Introductory Physics," pp. 111-114.
2. SEARS, FREDERICK E., "Physics for Secondary Schools," pp. 120-129.

CHAPTER XXII

WORK

The terms *force*, *work*, and *energy* are frequently confused and it is necessary that the distinction between them be understood. It has been seen in the previous chapter that a force, when not opposed by an equal force, will produce or change the direction of motion, and that when the force is balanced by an opposing force, no motion results. In other words, some forces are active while others are inactive. For example, when the chains of a hoist are pulled to raise a core plate from the floor, an active force has been set in motion; when a clamp is wedged on the flanges of a flask, the clamp is caused to exert a force which will produce no motion, even though the clamp be allowed to remain wedged tightly for years. In the case of the hoist, the moment the core plate starts to rise from the floor, work is being performed. Force acting through distance constitutes *work*.

Because work involves both force and distance, any measure of work must take account of both these things. Force is usually measured in pounds, and ordinary distances about a shop are usually measured in feet. A convenient measure for work, therefore, is the foot-pound. As defined in the science of physics, a *foot-pound* is the amount of work performed in raising one pound through a distance of one foot.

For all weights and distances, the amount of work performed is in direct proportion to the weight and the distance; thus, the work performed in lifting a 50-lb. core plate through a distance of 20 ft. equals 50×20 or 1,000 ft.-lb.

The formula is:

Force $\times$ distance = work

It may be remembered here that friction is also a force which acts as long as two bodies move in contact with each other. Neglecting friction, the work done in raising W through h

is $W \times h$ as illustrated in Fig. 10. If, however, the weight is pushed up with a force P , the work done is $P \times L$. Since the work done is the same, it is evident that $W \times h = P \times L$.

But lifting is not the only kind of work to be dealt with. In its mechanical sense, work is the overcoming of any resistance by force. If a loaded sand car is pushed along the transfer track, resistance is met; this is partly due to bearing friction and partly to rolling friction. The force of resistance, like any

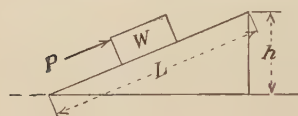


FIG. 10.

other force, may be measured in pounds, and the work of moving the car may be determined by multiplying the number of pounds needed to overcome the resistance by the number of feet the car is moved.

Thus, if a steady push of 125 lb. were required to overcome the resistance and the car were moved 50 ft., the work performed would amount to

$$50 \times 125 = 6,250 \text{ ft.-lb.}$$

In a similar manner, the work performed by cranes and hoists in moving castings, flasks, cores, or ladles may be easily calculated.

Work, like many another word, has several meanings. As explained in the previous paragraph, in its mechanical sense it means the overcoming of resistance. If resistance is overcome, motion is produced and work is performed; but if a force is exerted against a resistance too great for it to overcome, no motion results, consequently no work is performed. Thus, if a 10-ton crane hoist is attached to a 50-ton casting and the motor started, the electric current will cause the rotating part of the motor to turn over a few times till the chains tighten up, when the motor will stall and some current will be wasted in heating up the windings before the circuit breakers operate to shut off the current. No useful work is performed, although force has been exerted. There is, of course, a little work done in rotating the armature of the motor and in stretching the chains, but it is incidental merely to the main task which is the lifting of the casting, and which remains undone.

Problems

1. A casting weighs $2\frac{1}{2}$ tons. If it is raised 9 ft. above the floor, how much work is done?
2. The friction in moving a hand car is given as 30 lb. What work is done in moving it 40 ft.?
3. The door of a cupola is 15 ft. above the floor where the automatic feed cars are loaded. What force is necessary to pull one of these cars weighing 800 lb. up the incline 200 ft. in length to the charging door? (Refer to the chapter on the inclined plane.)
4. If the friction in the above problem is 45 lb., what work is done in overcoming it?
5. A casting weighing $1\frac{1}{2}$ tons is to be lifted 8 ft. How long an inclined plane must be used if a force of only 160 lb. is available?
6. A cope weighing 780 lb. is lifted 5 ft. What work is done?
7. How much work is performed in going up a 30-ft. flight of steps?
8. How much work is performed in filling a flask with 80 cu. ft. of sand if the average height to which the sand is raised is 2 ft. and sand weighs 120 lb. per cubic foot?

Topical Questions

1. May a man, by careful study of a job, reduce the amount of work needed for its accomplishment? Illustrate or explain.
2. If a push of 75 lb. is exerted for one minute, in an attempt to move a shop car and fails to move it, in the mechanical sense, has any work been done? In any sense, has any work been done? Explain.

Text References

1. HIGGINS, LOTHROP D., "Introductory Physics," pp. 133-135.
2. SEARS, FREDERICK E., "Physics for Secondary Schools," pp. 131, 145.

CHAPTER XXIII

ENERGY

In any up-to-date foundry, work is performed by many different agencies. Rammers, chipping hammers, and hoists are operated by compressed air; cranes, riddles, and elevators, by electricity; other apparatus by steam power; and occasionally some slow-moving and heavy machinery by water pressure. In air, steam, or water at suitable pressure, and in the electric current, there is the ability to perform work. This *ability to perform work* is called energy. While there is no essential difference between the energy from one source and that from another, it is customary to refer to the various forms of energy by referring to their sources; thus, there is muscular energy, mechanical energy, electrical energy, chemical energy, heat and light. With all these forms, foundrymen have to deal in the various phases of the business.

The various forms of energy can be converted one into another. We burn coal or coke in a furnace and the chemical energy of the uniting fuel and oxygen is converted into heat. If the fuel is burned in a foundry melting furnace, the heat is applied directly to the melting of metal. If the furnace is under a steam boiler, the heat causes water to expand into steam and is thus converted into mechanical energy. This mechanical energy of the steam is applied by means of a steam engine to the work of the plant and, as it performs its appointed tasks, a part of it heats the engine and the air and so is scattered. At every conversion of energy into another form, there is a certain proportion which cannot be recovered for use. The greatest loss occurs when the fuel is burned, since a large part of the heat goes up the stack or is lost by radiation from the furnace walls.

Since energy is the ability to do work, the units of energy are the same as the units of work, the most commonly used

being the *foot-pound* in the English system and the gram-centimeter or the kilogram-meter in the metric. In a previous chapter, it was learned that to raise a 50-lb. core plate through a distance of 20 ft. would require the performance of 1,000 ft.-lb. of work. For the performance of such a task, 1,000 ft.-lb. of energy would be required. If this same core plate should fall and its weight could be used to operate some suitable machinery, it would be found that in falling the 20 ft. it would give out just 1,000 ft.-lb. of energy. Of course, in such a test as this, allowance must be made for losses due to friction.

In converting energy from one form to another, some is always lost. It must not, however, be concluded that such lost energy has been destroyed. Energy is indestructible. That which is lost is merely converted into unusable forms. If one places his hand on the shell of a small motor, such as is used to operate riddles and other small machinery, he will notice, if it has been running for some time, that it is warm or even hot. This is due to the conversion of a part of the electrical energy into useless heat which escapes through the iron and shell into the air and is lost, although not destroyed.

The indestructibility of energy is referred to as the *law of the conservation of energy*. Since the dividing line between matter and energy has disappeared as a result of scientific study, the *twin laws* of conservation of matter and conservation of energy are known to be one law of larger scope. Practically, we are continuing to consider energy from different sources and matter of different kinds; though we may look forward to a time when energy will be produced industrially from certain changes in what is known as matter.

In order to understand the indestructibility of energy, not only the energy which escapes being utilized during the performance of work must be considered, but also the large amount of energy no part of which is being used at any certain time. This is because of the two different conditions in which energy may exist.

Energy, or the ability to do work, exists in two different conditions. The first is due to the position of an object and is called *potential energy*. The second, *kinetic energy*, exists

because some object is moving. A 5-lb. weight at a height of 10 ft. is capable of doing 5×10 or 50 ft.-lb. of work in falling. However, so long as it does not fall, the energy is still there. When the weight is on the ground, the energy is gone. Hence, the weight owes its energy to its position. This energy is called potential energy because it exists but is not being used.

The energy in motion, or kinetic energy, depends upon the velocity of the object. The greater the velocity, the greater is the energy. It takes more energy to move a wheel faster. A faster moving wheel, therefore, can do more work than a slower one.

E = kinetic energy in foot-pounds

W = weight of moving object in pounds

v = velocity of moving object in feet per second

The kinetic energy of a moving object is given by the expression:

$$E = \frac{Wv^2}{64} \text{ foot-pounds}$$

Suppose a rammer is moving 5 ft. per second when it strikes the sand. When the rammer comes to a stop, all the energy of its motion is converted into the work of ramming the sand with the exception of the small amount lost as heat because of the collision of the rammer and sand. If the rammer weighs 40 lb. then the energy converted into work is:

$$E = \frac{Wv^2}{64} = \frac{40 \times 5 \times 5}{64} = 15\frac{5}{8} \text{ ft.-lb.}$$

Thus, it is seen that the energy of a moving object depends upon the weight and the speed of the object. It must be understood, that to give an object its speed, the same amount of energy must be used that is obtained from the object when it is stopped. The rammer must have $15\frac{5}{8}$ ft.-lb. expended on it before it will reach a speed of 5 ft. per second.

The velocity of a falling body increases during falling, and the final velocity is found by the formula $V = gT$, V being feet per second, g being the accelerating effect of the force of gravity measured in terms of the increase in velocity (as so many feet per second) in one second, the value

of g being stated as 32 feet-per-second, per second. T refers to time in seconds.

To find the energy of a falling body it is necessary to know, in addition to its weight, either its final velocity or the time consumed in falling, or the distance fallen. The energy of a falling body may be found by the formula $E = SW$ in which S is the distance fallen in feet.

The foundry business is but one side of a many-sided industrial system. On every other side, is found the same necessity for constant supplies of energy to perform the tasks which, in an earlier age, were performed by the muscular energy of men or animals. The whole modern industrial life is dependent upon steady and very large supplies of energy. It is estimated that every person in average surroundings nowadays has service equivalent to that which 35 servants would have given in the old days before engines, motors, etc., were known. Every man or boy who is employed in the foundry, or in any other branch of industrial work, will find it to his profit to be as fully informed as possible on a subject of such vital importance to the whole industrial world. Several references are given at the end of this chapter to books that will furnish information of this sort; and the trade magazines also publish frequent articles along the same line.

Problems

1. A mold weighing 520 lb. is raised 8 ft. above the floor and held there for a short time. What is its potential energy?
2. Plot a curve for Problem 1, with energy as the ordinate and distance raised as abscissa, the weight being constant, using as units, abscissa 1 in. = 1 ft.; ordinate 1 in. = 1,000 ft.-lb. (Reference may be made to the subject of Tables, Diagrams and Curves in mathematics.)
3. A hand car moves 5 ft. per second and weighs 520 lb. What energy does it require?
4. A mechanical drop weighing 2,000 lb. is usually raised to a height of 50 ft. before releasing. How much work is done in raising it to that position? How much energy is expended in doing so? How much energy will it deliver in falling the 50 ft.?

Topical Questions

1. Name as many forms of energy as you can which are employed in foundry work.

2. What form of energy is used in each of the following jobs: Shoveling sand? Ramming? Lifting flasks? Removing loose sand, etc. from molds? Drying cores? Operating cranes?

3. Explain how coal possesses energy, the ability to do work.

4. The process of melting requires a great expenditure of energy. Does this mean that actual work is performed on the metal in process of being melted? If work means the overcoming of resistance and the consequent production of motion, what motion is produced in the melting process?

5. In one brief sentence, state the distinction between energy and work in the scientific sense. Does this same distinction hold, practically, in regard to humans? Illustrate.

Text References

1. HIGGINS, LOTHROP D., "Introductory Physics," pp. 6, 134-135, 203.
2. SEARS, FREDERICK E., "Physics for Secondary Schools," pp. 204-207, 225-231, 292.

Reading Reference

SLOSSON, E. E., "Chats on Science," pp. 67-74, 88-89.

CHAPTER XXIV

POWER

Work in any foundry or other industrial establishment is done on a time basis. One works so many hours per day, and a definite amount of work must be done in each hour. All of the machines do a certain amount of work in a given time. The rate or speed of doing work is an important feature in all production. This rate of doing work is called *power*. Work is measured in foot-pounds; power is measured in foot-pounds per second or per minute. If we desire a machine to do 12,000 ft.-lb. of work in an hour, this means that the machine must do $12,000 \div 60$ or 200 ft.-lb. per minute. In other words, the machine must have a power of 200 ft.-lb. per minute. It is apparent that this machine is twice as powerful as another which can do the same work but requires twice as long. It is only half as powerful as a machine which has a power of 200 ft.-lb. per half minute.

Power is generally measured in units called horsepower. One horsepower is the same as 550 ft.-lb. per second or 33,000 ft.-lb. per minute. Consequently, a machine of 5 hp. is capable of doing $5 \times 33,000$ or 165,000 ft.-lb. of work every minute that it is in operation. This means that it will raise a weight of 1,000 lb. through 165 ft. in one minute. To obtain horsepower, the work done in foot-pounds per minute is divided by 33,000.

Problems

1. A motor has a rated horsepower of 5.2. How much work in foot-pounds will it do in 8 min. after its full horsepower is developed?
2. A crane lifts a casting of 11,000 lb. through 9 ft. in 40 sec. What horsepower is expended?
3. A crane carried a 4-ton casting 120 ft. If 5 hp. was used, how long did it take?
4. A man shovels 3 tons of sand to an average height of 4 ft. in 1 hour. What horsepower is expended?

5. A machine has a horsepower of 4.3. What weight will it move through 6 ft. in 2 min?

6. A rammer weighing 3 lb., makes 600 blows per minute, and the average stroke is 4 in. What is the horsepower?

Text References

1. HIGGINS, LOTHROP D., "Introductory Physics," pp. 136-137.
2. SEARS, FREDERICK E., "Physics for Secondary Schools," p. 154

CHAPTER XXV

MOTION

Every problem that arises in the foundry trades involves the three factors: *material*, *energy*, and *motion*. Some properties of materials have been studied in the earlier chapters of this book, and a brief study of energy has just been completed; attention will now be turned to the subject of *motion*.

Authorities on the subject of physics state that motion is *continuous change of position* and that a body which is in motion has *direction* and *velocity* or *speed*. Direction is understood to be in a straight line. A body moving in a curve is undergoing *continuous change of direction*. Velocity is usually expressed in the ordinary units of length and time as, for example, feet per second, feet per minute, or miles per hour. Motion is referred to as uniform or variable with reference to its velocity. Motion is said to be *accelerated* when its velocity is increasing, or *retarded* when its velocity is decreasing.

An examination of the operations of lifting and moving a heavy mold or casting by means of a crane will illustrate the various modifications of motion in a practical way. As learned by observation in the foundry, as well as from the recent chapter on Inertia, a heavy load cannot be lifted safely by starting the hoist motor at full speed. If the load were anything approaching the maximum capacity of the hoist, its inertia might be sufficient to snap the chains. If the load were a heavy cope, the inertia of the mass of sand would be sufficient to overcome its adhesion to the sides and bars and a ruined mold would result. The speed of the hoist, therefore, is very slow at the start, the chains are tightened carefully and great pains are taken to avoid any sudden increase in the velocity of the rising load. When the load is clear of

all obstructions, the trolley motor and bridge motor are started, care being used here also to accelerate the load very gradually until a safe speed is attained. This speed is maintained until near the end of the travel, when the load is brought gradually to a stop with the same care used in starting. The load is then lowered carefully into place.

Unconsciously, every normal person learns a few truths about motion. It is known that when something falls, it is the shock of stopping which does the damage, if any is done. Sudden acceleration or sudden retardation of motion is apt to be harmful to the moving body. In all machinery, whether for foundry or for other lines of work, devices are used to control the acceleration and retardation of moving parts so that they pass from one velocity to another without shock to themselves or other parts of the machinery. Cranks, cams, and springs are some of the devices used.

So far, consideration has been given only to motion taking place in a straight line which may be produced by a single force or by several forces acting at the same time. Motion along a curved line is always produced by at least two forces acting together. As the rack of a small core oven is swung in or out, its motion seems to be the result of the single push or pull given it, but this is not the case. The resistance of the hinge is as truly a force as the push or pull imparted, and the combined effect is to swing the rack in a curve. All *curvilinear motion* will be found to be produced by at least two forces, one tending to move the body in a straight line, the other restraining it and holding it at the same distance from the center of motion. Naturally, if a body, such as a flask, is swung too violently in a curve, the restraining force may lose its grip on any loose material, such as the sand, with disastrous results. The force which pushes the body forward and tends to push it outward at a tangent is called *centrifugal* force; the restraining force which holds it to the center is called the *centripetal* force.

It must be understood that the subject of motion is one which can be barely touched upon in this brief chapter. The laws governing variable motions alone would occupy far more space than is available. These laws, however, may be found under the subjects of motion and acceleration in any good

textbook on physics, and a description of the various devices used to control motion may be found in any textbook on machine design.

Topical Questions

1. Give examples of uniform motion; variable motion.
2. In the case of a large assembled mold which is lifted and passes from a state of rest to a velocity of 10 ft. per second, what is the source of danger and how may the danger be guarded against?
3. Ascertain the maximum speed of the cranes in the place of your employment, both for hoist and travel of bridge and trolley.
4. In what way, if any, does the risk in accelerating too rapidly differ from the risk in retarding motion too rapidly? Explain fully.
5. In lifting a load, what relation has the capacity of the hoist to the permissible speed of acceleration of the load?
6. What effect would extremely rapid uniform motion in a straight line have on a fragile body such as a mold?
7. Would a similar speed in a circular path have any different effect? If so, what?

Text References

1. HIGGINS, LOTHROP D., "Introductory Physics," pp. 91-94, 128-132.
2. SEARS, FREDERICK E., "Physics for Secondary Schools," pp. 17-19, 120, 192-196, 217.

CHAPTER XXVI

GRAVITY AS A FORCE

The force of *gravity* and its operation have already been discussed under the subject of weight. This force, acting constantly upon every particle of substance in or on the earth, is so familiar that its practical utility is apt to be forgotten, much as are the various uses of the air breathed. The uniformity of the force of gravity, as well as its unfailing operation, makes it a valuable aid in industrial work. Many of the functions performed by this force must be called directly to the attention, or they would be overlooked because of their very commonness.

Among the things which would be impossible without the force of gravity, is the operation of the cupola. The whole process here depends upon the charging of material above which passes down through the stack. Screening of sand and pouring of metal are other operations which are only possible through the agency of gravity. These are cases where the action of gravity is one of the conditions of working, taken advantage of by industry just as they might be taken advantage of by an ignorant barbarian who has much the same practical knowledge of weight.

The intentional use of gravity as a means for moving materials is very old. The earliest use, perhaps, was in providing aqueducts to carry water by gravity and skids to carry heavy weights. A very common method about industrial plants is to pump water into an elevated tank from which it is distributed by gravity through pipes. The same principle is employed in sand tempering, conveying, and distributing machinery, the tempered sand being dumped by conveyors into overhead bins, from which the molder obtains it by opening a gate and letting the sand fall into his flask or upon his bench. Coal, coke, and other materials used in foundry work are, also, handled in this manner.

It has been noticed, no doubt, that in order to utilize gravity in handling material, gravity must first be overcome in placing the material where gravity can move it. This is an instance in which energy is stored up by raising the material in bulk and then utilizing that energy, as it is required, by opening the gate and permitting gravity to pull down a supply of sand, coal, or coke. Energy which depends upon the position of a body is sometimes referred to as *energy of position* or *potential energy*. Any elevated weight possesses potential energy which may be released by causing it to fall. Weighted levers on molding machines are arranged to take advantage of this sort of energy. Most of the practical applications of this energy are applications of the force of gravity.

Topical Questions

1. Explain the part which gravity plays in the production of the draft in a furnace.
2. What force is utilized in a tumbling barrel for cleaning castings? How?
3. What two forces are utilized in jolting?
4. Can a body be insulated from gravity as it is insulated from electricity? Defend your answer.
5. What would be the possible effect of such insulation from gravity?

Text References

1. HIGGINS, LOTHROP D., "Introductory Physics," pp. 18-20.
2. SEARS, FREDERICK E., "Physics For Secondary Schools." pp. 19, 192.

CHAPTER XXVII

HEAT

Heat is one of the forms of energy; one is made aware of it through his sense of touch. One can readily feel that an object is hot or merely warm. Just what heat is, is not known, but its effect can be seen in change of temperature.

In the foundry industry more energy is used in the form of heat than in any other form. The melting of metal, the drying of molds, cores, ladles, and furnace linings, the annealing of castings, and the warming of the buildings in winter—all call for large quantities of heat; and some of these uses necessitate accurate means of measuring the intensity and quantity of heat used.

By far the greater part of the heat used in foundry work is derived from the combustion of coal, coke, oil, and gas. In some places, melting is done by means of electricity, but at the present time heat from this source forms a small percentage of the total. Combustion of fuels, as a source of heat, is at present one of the important problems in industry, and it is considered in more detail in later chapters.

Measure of Heat.—Whatever the source of heat, this form of energy must be fairly accurately measured in order to insure any degree of control. Various methods have been developed for measuring both the intensity and the quantity of heat.

The subject of the measurement of temperature or *intensity of heat*, by means of thermometers, has already been studied briefly. Since the temperatures of furnaces range from the soft-metal pot at 500 to 600° F. to high test iron production, in which the temperature of the metal may reach 3000° F., it is obvious that the thermometer would be of little use in most foundries. For such work instruments called *pyrometers* are used. These are of many types and a detailed description of them would be beyond the range of this chapter. Those in

common use for very high temperatures are in general of two types; the *optical pyrometer* and the *thermoelectric pyrometer*. The first named is an instrument by means of which the brightness of the light coming from a heated object is compared with a standard source of light. The second depends upon the extremely small current generated by the action of heat on the junction of two wires of two dissimilar metals. These wires are protected by a tube of very refractory material, the joint being at the extreme end. This end, called the *hot end* or *fire end*, is placed in the furnace; or, in the case of certain alloys and metals, it is dipped beneath the surface of the molten metal. The outer or *cold ends* of the wires are connected to an electric measuring instrument.

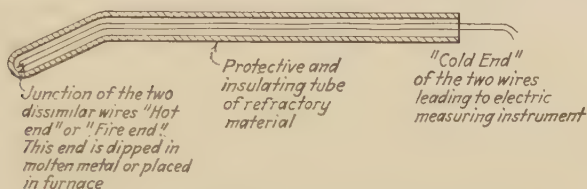


FIG. 11.—Diagram of thermoelectric pyrometer.

In order to measure the *amount of heat* it is necessary to use, as a standard, the amount of heat absorbed by a definite weight of some substance. Water provides such a unit. It absorbs a relatively large quantity of heat, and instruments can be devised so that the heat to be measured can very largely be absorbed by water of known temperature and amount. Such an instrument is called a *calorimeter* or measure of heat. The words *calorie* and *calorific* are derived from a word meaning heat.

The heat units of coal, coke, oil, and other fuels are determined by careful tests on accurately weighed specimens. Many concerns provide for these tests on all fuel purchased, and refuse to accept that which fails to reach a certain standard provided in their contracts.

Two units for the measure of the quantity of heat are in common use.

1. The calorie is the quantity of heat necessary to raise the temperature of one gram of water one degree Centigrade.

2. The British thermal unit (B.t.u.) is the quantity of heat required to raise the temperature of one pound of water one degree Fahrenheit.

Specific Heat.—The quantity of heat required to raise the temperature of equal amounts of various substances differs widely. It requires about nine times as many heat units to raise the temperature of a pound of water one degree Fahrenheit as it does to raise the temperature of a pound of iron one degree. A mass of heated water thus becomes a reservoir of heat and this accounts for its use in heating systems. In this matter of absorption of heat, water is taken as a standard. The ratio between the quantity of heat necessary to raise the temperature of a given substance one degree, and the quantity necessary to raise the temperature of an equal weight of water one degree, is known as the *specific heat* of that substance. Water, taken as the standard, has a specific heat of 1.00. For example, a certain amount of water requires 1 B.t.u. of heat for each degree of rise in temperature; an equal weight of copper takes 0.094 B.t.u. and of iron requires 0.130 B.t.u. This is because the specific heat of copper of this particular composition is 0.094 and of the iron is 0.130. If the specific heat of a substance is 0.225, then one pound of the substance requires only about one-fourth as many B.t.u. to raise it one degree as to raise one pound of water one degree.

The following table gives the specific heat of a few common substances as stated on page 1277 in "Machinery's Handbook."

TABLE VI.—SPECIFIC HEAT OF A FEW COMMON SUBSTANCES

Aluminum.....	0.214	Lead.....	0.031
Antimony.....	0.051	Mercury....	0.033
Brass.....	0.094	Nickel.....	0.109
Brickwork.....	0.200	Steel.....	0.116 to 0.117
Copper.....	0.094 to 0.101	Tin.....	0.056
Ice.....	0.504	Zinc.....	0.095
Iron, cast.....	0.130	Water.....	1.000
Iron, at temperatures 1382 to 2190° F.....	0.213 to 0.199		

Republished, by permission, from "Machinery's Handbook," copyright 1914, 1924, by The Industrial Press, New York.

Specific heat is of great importance to the foundryman whose business involves the raising of metals to melting temperatures. From the table it is apparent that it requires more heat units and consequently more fuel to raise a quantity of iron to a temperature of 1000° F., than it requires to raise an equal weight of copper to the same temperature, and that an equal weight of aluminum would require nearly twice as many heat units as the iron.

Latent Heat of Fusion.—When any metal, such as iron or copper, has absorbed enough heat to raise its temperature to the melting point, it commences to melt. If heat is continually added to it, it will eventually all melt, but during the melting process its temperature will remain unchanged at the melting point, in spite of the quantity of heat absorbed.

The heat so absorbed at the melting point without change of temperature is referred to as the *latent heat of fusion*. Thus it is seen that the addition of heat to a substance does not always result in a rise of temperature. Until the melting point is reached, the rise in temperature continues with every heat unit added; but once the melting point is reached, the effect of any further added heat is not to raise the temperature but to convert part of the substance into a liquid. After a solid has been completely liquified, the rise in temperature is resumed with any further addition of heat.

This subject of the fusion and cooling of metals, and the absorption of heat in melting, as well as its emission during the cooling process, can barely be touched upon here. Many discussions of it will be found in up-to-date works on metallurgy, and some of these should be read by the student as soon as his growing knowledge will permit him to understand them.

The following table indicates the variation in the amounts of heat required for the melting of the same weights of different substances. These same figures indicate, also, the amount of heat that is given up, or becomes visible, when one pound of any one of the materials mentioned passes from the liquid to the solid state.

The effect of this heat of fusion given up by a liquid changing to a solid is sometimes seen in a foundry when a very hot, dull casting brightens in color, showing that additional heat

TABLE VII.—LATENT HEAT OF FUSION¹

Substance	B.t.u. per Pound
Ice.....	143.33
Aluminum.....	138.24
Copper.....	75.6
Iron, gray.....	41.4
Iron, white.....	59.4
Iron, slag.....	90.
Phosphorus.....	8.94
Lead.....	9.65
Silver.....	37.92
Sulphur.....	16.87
Tin.....	25.2
Zinc.....	50.63

¹ Reprinted by permission from the 10th Ed. of Kent's "Mechanical Engineers' Handbook," p. 598.

has been gained from some source. Use is made of the latent heat in water when pans of water are placed in a cellar to protect vegetables from freezing, although of course the amount of heat thus available is limited.

Latent Heat of Evaporation.—As the temperature of a liquid is increased, a point is reached at which it may undergo a change from the liquid to the gaseous state. We find that here again, if the liquid vaporizes, the temperature remains at a standstill until all the material has passed into the gaseous state. Heat is absorbed in changing the material from a liquid to a gaseous state, just as it is absorbed in changing it from the solid to the liquid. Heat so absorbed, in changing a substance at its boiling point from the liquid to the gaseous state, is referred to as the *latent heat of evaporation*.

The table below shows that it takes nearly a thousand times as much heat to change water to steam with no sensible change in temperature as it does to raise the same weight of water one degree in temperature when the heat absorbed is sensible, that is, not latent. This very great heat of evaporation of steam accounts for the value of steam as a source of power. It accounts also for the painful effects of even a slight steam burn.

What becomes of the heat that is absorbed in latent form as heat of fusion or heat of evaporation? According to the

TABLE VIII.—LATENT HEAT OF EVAPORATION¹

Liquid	B.t.u. per Pound
Water.....	966.6
Alcohol, grain.....	371.
Ether.....	162.8
Turpentine.....	133.

¹ Republished, by permission, from "Machinery's Handbook," 5th Ed., p. 1276, copyright 1914, 1924, by The Industrial Press, New York.

law of the conservation of energy, it is known that this heat continues to exist. The differences in molecular motion in solids, liquids, and gases explain, quite simply and adequately, in what form the latent heat continues to exist.

It will be remembered that all matter is made up of molecules. These molecules are in constant motion, except in the theoretical condition of absolute zero, which is several hundred degrees below the freezing point of water. This molecular motion is associated with heat.

In solids, the motion of the molecules is limited to vibration, each molecule keeping its same relative position; hence solids tend to retain their form. In liquids, the molecules move longer distances and more freely. This greater motion naturally requires more heat and it accounts for the greater fluidity of these substances. In gases, the molecules tend to move away from each other indefinitely and the amount of heat required for this is great. The relative movement of the molecules in solids, liquids, and gases accounts for the fundamental differences between these three states in which matter exists. It accounts in part, also, for many of the familiar phenomena which are observed in the control of the material environment.

Transmission of Heat.—Heat is transmitted from one body to another by three methods: *Radiation*, *conduction*, and *convection*.

Radiation is the transmission of heat from a heated body to one separated from it by an open space; thus, the heat of a furnace is received as it is passed. *Conduction* is the transmission of heat from one body to another which is in contact with it, or between the parts of a body unevenly

heated. Thus a forging, one end of which is in the reheating furnace, will, by conduction, become very hot at the outer end.

Convection is the transfer of heat in a fluid by movements of the fluid itself. The term fluid includes both liquids and gases. The movements result from the fact that the hotter portions of a fluid are of less density, due to their expansion, than the cooler parts. The hotter, lighter portions tend to rise and the cooler tend to sink because of this difference in density, and currents are thus set up.

In a ladle of hot metal exposed to the air at the surface, the hot currents rising to the surface become cooled, gain in density and sink to give place to fresh supplies of hotter and less dense metal. The movement of convection currents in a ladle of hot metal can often be clearly seen. Convection currents are also utilized to produce the circulation of warm air in houses heated by warm air furnaces.

Topical Questions

1. When metal is exposed to a melting temperature in a furnace, why does it not melt immediately?
2. Can heat energy be used over and over? Why?
3. From your answer to No. 2, state what is the real distinction between useful heat and waste heat.
4. Give examples of useful heat and waste heat and show, if possible, how waste heat may be entirely avoided.
5. What terms are used in reference to the intensity of heat? The amount?
6. What term is used to refer to the relative quantity of heat required to produce a given intensity of heat in any substance?
7. Give several common examples, preferably from the foundry, of radiation, conduction, and convection, and state whether the heat involved is being used or lost in the process.

Text References

1. BRADBURY, ROBERT H., "A First Book in Chemistry," pp. 102-103.
2. HIGGINS, LOTHROP D., "Introductory Physics," pp. 151-213.
3. SEARS, FREDERICK E., "Physics for Secondary Schools," pp. 285-301, 322-335.

CHAPTER XXVIII

LIGHT

Light, like heat, is a form of energy. It is impossible by any known commercial process to produce light without also producing a considerable amount of heat, which is in this case waste energy. Cold light is being sought in some research laboratories; and apparently cold light is already produced in nature by a number of animals such as deep sea fish and our familiar fireflies. It is impossible also to produce any intense degree of heat without the emission of light. This close relation of light and heat suggests one of the important uses of light—that of gauging the temperatures of materials at or near melting heat.

White light is really a mixture of all colors. This can be proved by passing a beam of white light through a triangular-glass prism. We find that the white light has been separated into a series of colored bands which shade gradually into each other. The primary colors are violet, indigo, blue, green, yellow, orange and red. This color band is called the spectrum, and the colors always appear in the same order, which is the order of their frequency of vibration.

Heat vibrations are of a lower frequency than those of light; consequently, when a body such as a piece of metal is subjected to high temperature the rising frequency of vibration of its molecules causes it first to get warm, then hot, and, finally, to emit light when very hot. As the temperature approaches 1000° F. the metal shows red, and as it becomes hotter one color after another is added until at about 2700° F. it is emitting every color vibration, and consequently appears white.

Figure 12 is a diagram showing the manner in which the spectrum is formed. The reasons for its formation involve a knowledge of higher mathematics, but one fact explains it so far as is necessary at this time. This is the fact that rays

of light passing from one transparent medium, such as air, into another, such as glass, or vice versa, are bent from their path, and that each color is bent at a different angle.

In the foundry, up to a generation ago, the heater judged the temperature of metal entirely by eye. Some men became expert at judging temperatures. In modern practice, however, it is necessary that some uniform method be used, because it is found that even a few degrees variation in temperature may produce great variation in the structure of the metal when it is cooled.

For metals that require moderate degrees of heat, an electrical pyrometer, such as that described in a previous chapter, is used; but for taking the temperature of metals of higher melting points such as iron or steel, the optical pyrometer is generally used. In the optical pyrometer, the heated metal

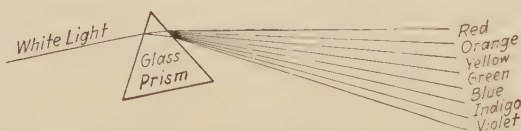


FIG. 12.

is viewed through a small telescope in the focus of which is a minute filament heated by the current from a small battery. The current can be adjusted to produce any desired temperature in the filament, which, of course, glows with the corresponding color. The glow of the filament, seen against the hot metal, is adjusted until filament and heated metal are the same color when, of course, the filament becomes invisible. A scale shows the amount of current used on the filament and the corresponding temperature.

A material through which light may pass freely is said to be transparent. Glass, water, and most gases are transparent in varying degrees. Some substances permit light of certain colors to pass but absorb others, and thus prevent their passage. Colored glass is such a substance. Red glass absorbs all colors except red which it permits to pass. Blue glass permits the blue rays to pass, absorbing all the others.

Topical Questions

1. Light has a speed of 186,000 miles per second. The number of vibrations of violet light is about double that of red light. What does this prove as to the length of the wave for each color? Refer to Fig. 13.
2. How would you measure the temperature of molten tin? Brass? Steel? Zinc? Aluminum?



FIG. 13.

3. Is molten metal usually at proper pouring temperature when it is run into the ladle? Explain.
4. Why do foundrymen use blue or violet glasses rather than red or orange glasses for inspecting very hot furnaces?

Text References

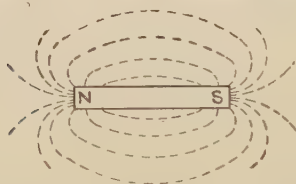
1. HIGGINS, LOTHROP D., "Introductory Physics," pp. 341-346, 383-386.
2. SEARS, FREDERICK, E., "Physics for Secondary Schools," pp. 454-456.

CHAPTER XXIX

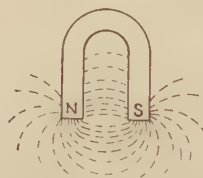
ELECTRICITY AND MAGNETISM

Everyone is familiar with many of the applications of electricity and has, no doubt, seen an ordinary horseshoe magnet. There is a close relationship between electricity and magnetism.

If a sheet of white paper is placed over a magnet and iron filings sifted on the paper, they will arrange themselves in regular lines somewhat similar to the dotted lines in Figs. 14 and 15. The pattern formed by the filings indicates



Bar magnet.



Horseshoe magnet.

FIGS. 14 AND 15.—Permanent magnets.

the existence of a field of force extending from one pole of the magnet to the other. For the sake of clearness, lines of force are said to pass from the north pole of the magnet, *N*, to the south pole, *S*.

These imaginary lines of force, which represent a very real field of force, are able to penetrate some materials more easily than others. Such materials are said to be more *permeable* or to have a higher *permeability*. Soft iron is about the most permeable material known. Any form of iron or steel is relatively high; air is very low. If a piece of soft iron were placed between the poles of the magnet, Fig. 15, the lines of force would seem to be drawn together to pass through the piece of iron. This is because the iron is so much more permeable than the air that the lines of force select the iron as the easiest path from one pole to the other.

Permanent magnets were mentioned in the previous paragraph. These are always of hard steel. If another piece of hard steel, such as a knife blade, is rubbed on a permanent magnet, it also will become magnetized. If, however, a piece of soft iron is rubbed on a magnet, the soft iron will only be affected while in contact with the steel. When it is removed it will lose its *induced* magnetism. But if a coil or *helix* of insulated wire is wound on a soft iron core, as in Figs. 16 and 17, and a current of electricity is passed through the wire, the soft iron core will become magnetized and will retain its magnetism so long as the current passes.

The relation between direction of current and position of poles is shown by the two sketches. It may be remembered by what is called the *right-hand rule*. If the coil is grasped

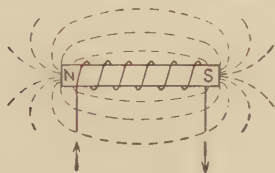


FIG. 16.

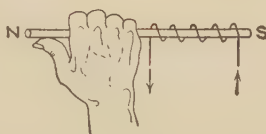


FIG. 17.

Figs. 16 and 17.—Principle of the electromagnet.

in the right hand so that the fingers point in the direction of the current which flows through the wire, the thumb will point to the *N* pole of the core. This is clearly shown in Fig. 17.

The method by which electric currents are produced may now be considered. Two methods are in common use. The first is by chemical action in an apparatus known as a battery. The essential elements of a battery cell are two dissimilar plates, generally of copper and zinc or carbon and zinc, and a fluid in which they are immersed, called an *electrolyte*. A description of the action of the electric battery may be found in the reference books named at the end of this chapter. The use of batteries is limited to very small power requirements, such as flash lights, telegraph and telephone work and ignition systems for gasoline engines. Where necessity demands the use of batteries for larger power units, such as in submarines, the power is very expensive.

The second method of obtaining electrical energy is by the conversion of mechanical energy. If a wire is moved across the field of force of a magnet in such a way that it cuts the lines of force, the magnetic field, in some way which is not fully understood, causes a current of electricity to traverse the wire. If the wire be made in the form of a loop, such as W in Fig. 18, and the loop be rotated about the axis AB in the direction of the arrows $r r$, a current of electricity will pass through the loop in the direction of the arrows, $s s s$.

When the plane of the loop is perpendicular to the direction of the lines of force, F , the number of lines of force passing

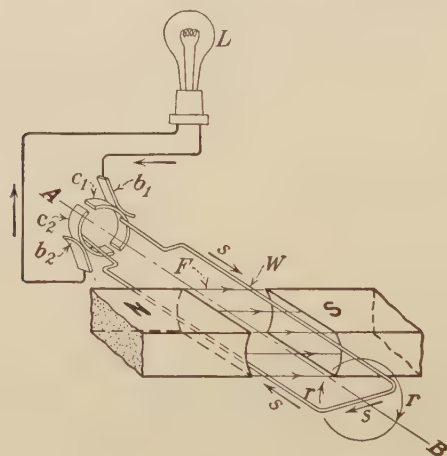


FIG. 18.—Principle of the generator.

through the loop will, for a brief period, be nearly constant, and the electrical impulse exerted in the loop will therefore be nearly zero. As the loop rotates from this position, it will cut the lines of force at a rapidly increasing rate until a maximum impulse is reached when the plane of the loop is parallel to the lines of force. The rate at which the number of lines of force passing through the coil is made to increase or decrease, determines the strength or *pressure* of the impulse. This is called the *voltage*. The size of the wire in the loop, and the voltage induced in it, determine the amount of *current* that passes through it. The amount of current is

measured in *amperes*. The resistance the wire offers to the passage of the current is measured in *ohms*.

If I = current in amperes, E = pressure in volts, and R = resistance in ohms, the relationship between the three may be expressed by the following formulas:

$$I = \frac{E}{R} \qquad E = IR \qquad R = \frac{E}{I}$$

These formulas apply to any constant direct current electrical circuit (or any circuit containing only resistance). Thus if we know the voltage in a power line to be about 110 and measurement tells us that the lamps are taking about 0.9 ampere each, applying the above formula, we have for the resistance of each lamp:

$$R = \frac{E}{I} = \frac{110}{0.9} = 122 \text{ ohms.}$$

The amount of power used depends upon both the amount of current, I , and the voltage. Power is measured in *watts*. A watt is the power produced by a current of 1 ampere at 1 volt. The formula for power is as follows:

Watts = EI . Since power is generally employed in much larger units than single watts, a larger unit called the *kilowatt* is used. The *kilowatt* is 1,000 watts. It is greater than the horsepower. The relations between kilowatt and horsepower are as follows:

$$1 \text{ kw.} = \frac{1,000}{746} \text{ hp. or } 1 \text{ hp.} = 0.746 \text{ kw.} = 746 \text{ watts.}$$

If the current generated by the simple generator, Fig. 18, be permitted to flow unchanged into the external circuits supplying the lamps, motors, and other appliances, it will be an alternating or A.C. current. This is due to the fact that the relationship between direction of magnetic lines of force, direction of motion of the wire loop, and direction of current induced in the loop are always the same. It is clear, then, that every time the loop is reversed by turning 180 degrees the direction of the current in the loop must reverse in order to maintain the relationship of the three things referred to. If it is desired that the current in the external circuit be in one direction, a direct current, D.C., commutator is used.

This is shown in its simplest form at c_1 and c_2 , Fig. 18. The current is taken from these commutator segments by sliding contact pieces of copper or carbon, b_1 and b_2 . Since the commutator reverses with the rotation of the loop, the direction of the current in the external circuit is unchanged.

In a modern generator, many such loops on a core of soft steel are rotated between the poles of an electromagnet, and a nearly continuous impulse is produced.

Alternating current (A.C.) is used for most commercial purposes such as lighting and power. It is more economical, because alternating current may be transmitted at voltages as high as 100,000 volts, and then by means of very simple apparatus may be transformed down to any lower voltage desired; 110, 200, 440, and 550 volts are commonly used for various purposes. The first two are generally used for industrial power, such as the operation of general foundry machinery. Such power is usually alternating current. For crane operation direct current is generally, but not always, used. The ordinary practice is 230 volts, D.C. or 440 volts, A.C.

In many foundries and steel plants, electric reducing and melting furnaces are used. These may use direct current or alternating current. In some, notably the larger electric melting furnaces, the heat is generated by arcs, similar in principle to an arc lamp but immensely more powerful. The arc depends upon the power which an electric current possesses to continue flowing after a gap has been created in the circuit. If an electric circuit be interrupted or broken while current is passing, the current will form a bridge of intensely heated gases and will continue to pass the gap until it becomes too great for the voltage used. Carbon or other very refractory material is used for the points or *electrodes* between which the current leaps. For melting furnaces of the arc type, A.C. is employed at low voltage, usually about 100. The amperage, which determines the amount of heat generated, depends upon the size, nature of charge, etc., and is very high.

In furnaces employing *heating elements* and depending upon the resistance of these for heat, the principle is exactly the same as that of the electric light or the little electric radiators

sold for heating bathrooms. The passage of an electric current through a conductor always generates heat. It is only necessary to adjust the resistance to the voltage used, to permit a sufficiently heavy current to pass. Too much current will melt the heating element, or *burn it out*, to use a common expression.

Topical Questions

1. How is the foundry with which you are associated lighted, with alternating current or direct current? What voltage is used?
2. How are the bridge cranes operated, with alternating current or direct current? At what voltage?
3. What kind of motors are used to operate sand riddles?
4. What is the source of the electric current used in the optical pyrometer?
5. Trace the steps by which the chemical energy in coal and oxygen is converted into electrical energy.
6. What is the principle of operation of the magnetic separator, which is used to extract the iron from brass foundry scrap and sweepings?

Text References

1. HIGGINS, LOTHROP D., "Introductory Physics," pp. 252-256, 266-272.
2. SEARS, FREDERICK E., "Physics for Secondary Schools," pp. 572-591.

PART V
APPLICATION OF FORCE

CHAPTER XXX

SIMPLE LEVERS AND LEVER SYSTEMS

A man cannot lift, unaided, a heavy mold or core or casting. To aid himself, he employs certain mechanical devices such as levers, pulleys, wedges, screws, and lifting tackle. Of all these devices, the simplest one is the lever.

A lever is a bar which is free to turn about a certain fixed point or *fulcrum*. Simple levers are divided into three classes according to the arrangement of the power, the fulcrum, and the load. The following sketch shows an example of each class. The arrows show the direction in which each force acts. The letters below are commonly used in connection with lever diagrams to indicate the respective elements:

P = Force applied

W = Load moved

l = Total length of the lever

a = Distance from fulcrum to load

b = Distance from fulcrum to point of application of force

c = Distance between the load and the point of application of force.

In an earlier chapter it was stated that work done by a given force is determined by the formula:

$$\text{Work} = \text{force} \times \text{distance}$$

The simple lever is a practical application of this principle. Referring to the sketch of the first-class lever, Fig. 19, it will be seen that the *power arm*, b , is shown considerably longer than the *load arm*, a . It will be clear that if b is three times as great as a , the point P will move three times as great a distance as W for a given movement of the lever about the fulcrum.

This is the advantage of a lever of the first-class. A comparatively small force moving through a considerable distance overcomes the resistance of a larger load moving

through a smaller distance. The same is true of the second-class lever. In the third-class lever, the exact reverse is true; here we wish to gain speed at some sacrifice of lifting force.

The method of calculating is as follows: Since the force applied multiplied by the distance through which it moves

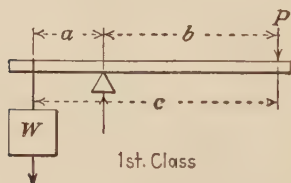


FIG. 19.

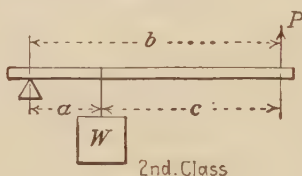


FIG. 20.

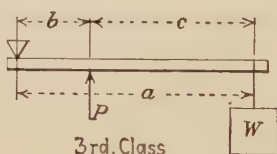


FIG. 21.

must be the equivalent of the load multiplied by the distance through which it moves, we have the equation:

$$aW = Pb$$

By transposition we have $W = \frac{Pb}{a}$

$$P = \frac{aW}{b}$$

$$a = \frac{Pb}{W}$$

and

$$b = \frac{aW}{P}$$

In addition to the simple lever, there are, occasionally, systems of levers. Such a system would be represented by Fig. 22 which represents an air cylinder operating a first-class lever having its fulcrum at F_1 . This lever in turn actuates lever number 2, which is a third-class lever having its fulcrum at F_2 . In such a system, the original force is that exerted by the air pressure in the cylinder. Knowing the various dimensions of the first lever, W_1 can be determined.

Since the load W_1 is the force transmitted to the second lever, $W_1 = P_2$, and W_2 is easily calculated from P_2 . Very few compound levers or lever systems are in use in connection with foundry apparatus, the exceptions being machines such as those used in molding and die casting. The great majority of levers used in any machinery are simple levers.

Levers need not be straight. Figure 23 shows a bell crank which is a bent lever. It is worth study. It will be noted that the angle at which the load is lifted has much to do with the force required on the bell crank; thus, if the

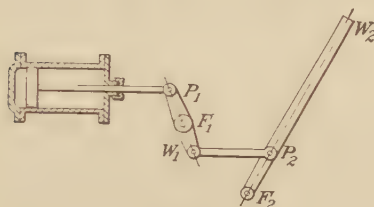


FIG. 22.

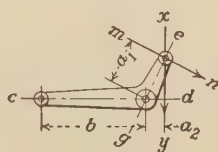


FIG. 23.

load is along the line mn , the load arm a_1 is at its greatest and the corresponding force will be great. On the other hand, a load applied along the line xy will have a load arm of only a_2 , calling for a considerably less force to lift it.

Exercises

Determine the missing quantity:

Class of lever	P	W	a	b
1	60 lb.	.....	1 ft.-0 in.	3 ft.-0 in.
1	.....	360 lb.	20 in.	24 in.
2	30 lb.	90 lb.	18 in.	
2	25 lb.	.....	6 in.	2 ft.-0 in.
3	.....	24	22 in.	6 in.
3	72	.....	24 in.	2 in.

Problems

1. A man wishes to raise the side of a core plate to place a chain. Using a pinch bar, as in accompanying sketch, how much force must he apply to raise one side of the plate?

2. In handling a shovel, the left hand grasping the handle is used as a fulcrum, the right hand imparts the swing that sends the sand to its place. If 8 lb. of sand rest on the shovel at an average distance of 32 in. from the fulcrum, how much force must be exerted through the right hand grasping the shaft 18 in. from the fulcrum?

3. What force will be required to lift a load of 250 lb. in the wheelbarrow shown below?

4. It is found that a pull of 30 lb. is required to pull a 10d. (10 penny) nail using the hammer shown below. What was the resistance of the nail?



FIG. 24.

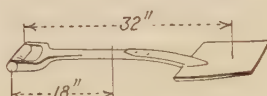


FIG. 25.

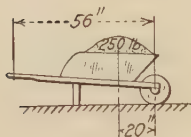


FIG. 26.

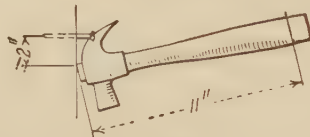


FIG. 27.

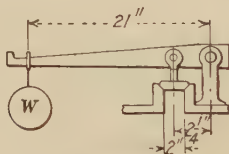


FIG. 28.

5. The air pressure in a foundry compressed air system is controlled by a safety valve shown here. What weight will be needed to keep the air pressure at 80 lb. per square inch?

Topical Questions

1. Explain with diagram how a clamping iron is used as a lever in clamping down a mold.

2. What is the reason so many strong men when starting to work in a foundry, cannot pick up and carry a hand ladle of iron? Explain.

3. In your study of levers, where should the second hand be placed on the shank of a hand ladle, assuming one hand to be on the handle?

4. Draw a sketch showing the application of a simple lever in carrying a hand ladle of iron.

5. If you were loading a wheelbarrow full of pig iron, where would you put the heaviest load, toward the wheels or toward the handles? Explain

by a sketch showing fulcrum, load, and force, and a and b (definitions in the first part of this chapter).

6. What are four advantages in the use of machines?

7. Describe the use of a lever in obtaining each of these advantages in the doing of some part of the work in a shop.

Text References

1. HIGGINS, LOTHROP D., "Introductory Physics," pp. 139-144.
2. SEARS, FREDERICK E., "Physics for Secondary Schools," pp. 112-119.

CHAPTER XXXI

TACKLE, BLOCKS, AND PULLEYS

The pulley is merely another form of lever. Referring to Fig. 29, it is seen that a pulley may be regarded as a series of levers having a common fulcrum, the center, which comes into action in succession as the rope, chain, or belt moves. The pulley, like the lever, is used to lift weights which are beyond the unaided strength of the workman. A number of

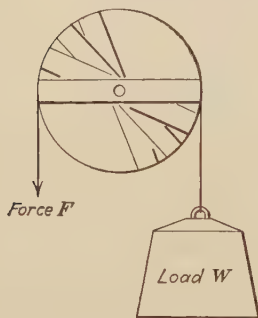


FIG. 29.

pulleys used in combination is called a pulley system. Two or more pulleys are often placed in a frame on the same axle. Such an arrangement is called a *tackle block*. In general the effect of using a pulley system is to permit a fast moving force to lift a much slower moving weight. Since it is known that:

$$\text{Work} = \text{force} \times \text{distance},$$

it will be clear that if a pulley system permits the load to move one-half or one-fourth as fast as the force which lifts it, the force need be only one-half or one-fourth as great as the gravitational pull or weight of the load.

In Fig. 30a, the pulley allows a casting to be lifted by a downward instead of an upward pull. The first pulley merely changes the direction of pull, the force F must equal the weight W . Figure 30b shows a movable pulley which may be used in combination with another pulley. This one is so arranged that if the force F moves up 2 ft., and the load moves up 1 ft., the rope S is decreased by 1 ft. This means that the end of the rope at F must travel 2 ft. to decrease the length of S 1 ft. From the knowledge of work, it is found that, in this case, F needs to be only $\frac{1}{2}$ of W when it travels

twice as far. Figure 30c shows how the direction of F is changed by adding a fixed pulley to a movable one as shown in Fig. 30b. However, it will be noticed that F must still move 2 ft. to lift W 1 ft.

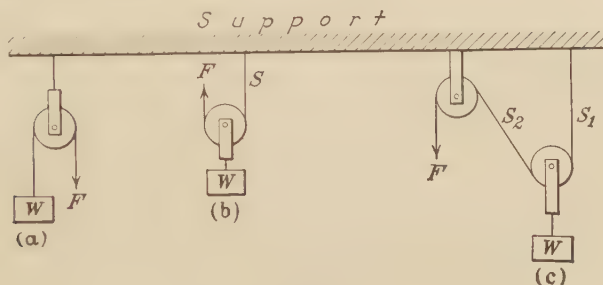


FIG. 30.

The comparison of distances travelled by the force and by the load is called the "mechanical advantage" (M.A.) of the pulley. Disregarding friction, in the first case the M.A. is 1, in the second and third cases, the M.A. is 2. The mathematical *mechanical advantage* of a lever or pulley is the ratio of the weight moved to the force used in moving it.

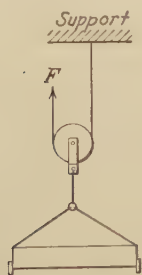


FIG. 31.

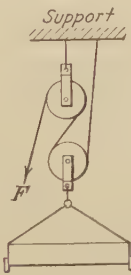


FIG. 32.



FIG. 33.



FIG. 34.

To increase the M.A. of a pulley, more pulleys are put into one block. The effect of this is to increase the number of ropes supporting the movable pulley. The M.A. of the pulleys in Figs. 32, 33, and 34 are, disregarding friction, respectively 2, 4, and 3. The M.A. of a system of pulleys

is the same as the number of supporting ropes provided the pulleys are of the same size.

The differential pulley is a type extensively used in foundries and other industrial establishments. A simple differential pulley system is shown in Fig. 33. Such devices are operated by chain, the rim of each pulley being grooved and lugged to fit the chain.

Referring to Fig. 35, pulleys *A* and *B* turn together about the fixed axis *D*. An endless chain passes about pulleys *A* and *B*, an intermediate loop supporting pulley *C* with the load *W*. A second intermediate loop is used for hauling up or lowering the load.

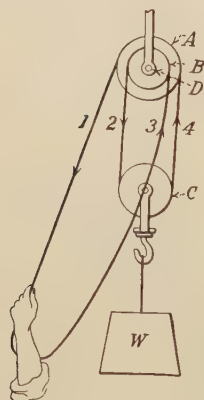


FIG. 35.

It is evident that as the chain at 1 is pulled down, 4 moves up and *tends to raise* *C* by shortening 4 and 2. Pulley *B*, however, is turning with pulley *A* and this *tends to lower C* and neutralize the raising effect of the upward movement of 4. But the radius of *B* is less than the radius of *A*, so that 4 moves up as much faster than 2 moves down as the rim speed of *A* exceeds the rim speed of *B*. Thus 4 constantly gains on 2 and the load rises at a speed

proportional to the difference between the rim speeds of the two pulleys.

If *P* is the force exerted on 1, *W* the load to be raised, *a* the radius of pulley *A*, and *b* the radius of pulley *B*, then

$$P \times a = W \times \frac{1}{2} (a - b) \quad P = \frac{W (a - b)}{2a} \quad W = \frac{2aP}{a - b}$$

In this discussion of pulleys no exact account of the friction of moving parts has been considered. This is not because friction may be neglected, but because it is a factor which cannot be known exactly in practical operations. It will reduce the efficiency of any mechanical device and especially such arrangements as the differential hoist described previously. A hoist used in a foundry is particularly apt to become inefficient because of friction, since sand and grit will get

into the mechanism and, by cutting the bearings, gradually throw the parts out of adjustment.

Problems

1. A molder desires to lift a core weighing 200 lb. What is the advantage of using the arrangement of Fig. 32? What force must he apply?

2. Using pulleys of Fig. 32, what weight could a molder lift by exerting a force of 120 lb.?

3. A casting weighs 320 lb. What force is required to lift it with the arrangement of Fig. 32?

4. A casting weighs 300 lb. Which system of pulleys (Figs. 31, 32, 33 or 34) would require the least force to lift the casting, and what is the saving in force over the next most effective system?

5. What weight could a man of 150 lb. lift by hanging to the end of the rope in Fig. 34? In Fig. 33?

6. A casting weighs 560 lb. What force is necessary to lift it with the pulleys of Fig. 33?

Text References

1. HIGGINS, LOTHROP D., "Introductory Physics," pp. 139, 141, 148-149.

2. SEARS, FREDERICK E., "Physics for Secondary Schools," pp. 117, 140-143.

CHAPTER XXXII

GEARS

The *gear*, like the pulley, is a sort of lever. In the pulley, motion and force are transmitted from one to the other by means of rope, chain or belting. In gears, it is transmitted by teeth on the rim of each gear which engage the teeth of other gears. If the teeth are properly designed, there is no slip and consequent lost motion with gears as there sometimes is with rope pulleys. Power is thus transmitted from one gear to another smoothly and continuously.

The gear or pinion from which power comes is called the driver, the one receiving the power is the driven gear. The pinion on the motor or engine is therefore always a driver.

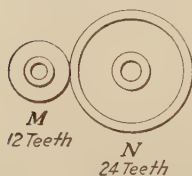


FIG. 36.

The gear on a pump or tumbling barrel which meshes with the motor pinion is driven. In Fig. 36, the pinion *M* may be regarded as a motor pinion. In this case it is the driver and *N* is the driven gear. In other cases, *M* may be the driven gear and *N* the driver. The relative sizes of gears depend upon what is to be accomplished. If increased power or

reduced speed is desired, the driver is smaller than the driven. On the other hand, if the driver is larger than the driven, there is less power and more speed.

The applications of gears and gear trains in the foundry are many. Large ladles are poured by this means; and many types of furnaces, especially brass furnaces, are tilted by means of gearing. Wire and rod straighteners, core making machines, sand mixers, tumbling barrels, cinder mills, air compressors and cranes are but a few of the many applications.

Referring to Fig. 36, it is evident that if *M* has 12 teeth and *N* has 24 teeth, one revolution of the larger will produce two revolutions of the smaller. That is, when two gears

are meshed the following equation expresses the relation between speeds, diameters, and teeth.

$$\frac{\text{Speed of large gear}}{\text{Speed of small gear}} = \frac{\text{diameter of small gear}}{\text{diameter of large gear}} = \frac{\text{number of teeth of small gear}}{\text{number of teeth of large gear}}$$

For example, a tumbling barrel, Fig. 37, is driven by a motor which is belted to the countershaft. The motor makes 1,200 r.p.m. and the ratio of the motor pulley diameter to the countershaft pulley diameter is 1:6. The countershaft carries a pinion which meshes with the gear on the barrel, the size of pinion and gear being as 1:8. What is the speed of the barrel?

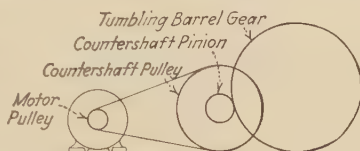


FIG. 37.

$$\frac{\text{R.p.m. of motor pulley, 1,200}}{\text{R.p.m. of countershaft, } x} = \frac{6}{1} \text{ or } x = \frac{1,200}{6} = 200 \text{ r.p.m.}$$

$$\frac{\text{R.p.m. of countershaft, 200}}{\text{R.p.m. of barrel gear, } x} = \frac{8}{1} \text{ or } x = \frac{200}{8} = 25 \text{ r.p.m.}$$

In case the shafts of the driver and driven gears are so far away from each other that the gears will not meet, a

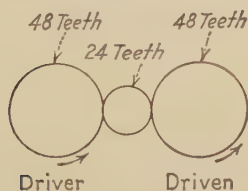


FIG. 38.

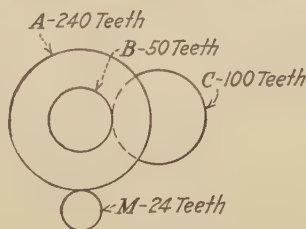


FIG. 39.

third and fourth gear may be put in to fill the gap. But these gears have no effect on the ratio of the driver to the follower. In Fig. 38, the middle gear does not change the ratio of the driver and driven; the ratio is 1:1. Intermediate gears may be put in for the purpose of changing the direction of rotation as well as of filling a gap.

Gears may be connected in a compound manner. In the case of the Bessemer converter, the gears may be connected

as in Fig. 39. The motor gear *M* turns 10 times to produce one revolution of the large gear *A*. The speed of *B* is the same as that of *A* since both are on the same shaft. Hence, 10 turns of gear *M* produces one turn of gear *B*. But one turn of gear *B* produces a one half turn in gear *C*. Thus, 10 turns of *M* make gear *C* turn a half revolution. This relation of gear *M* and gear *C* is understood by proceeding from one gear to the next in the series.

Problems

1. If the driver revolves at a speed of 50 r.p.m., what will the speed of the shaft be? (Fig. 40.)

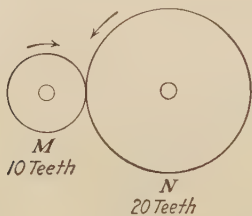


FIG. 40.

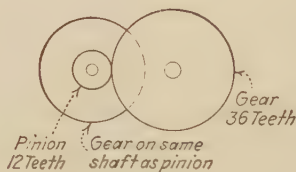


FIG. 41.

2. The shaft on a grinder must revolve at a speed of 1,200 r.p.m. The gear on the shaft has 12 teeth while the driver has 36 teeth (Fig. 41). What must the speed of the driver be?

3. Suppose the driver gear has 36 teeth and a speed of 80 r.p.m., and the shaft has a speed of 1,600 r.p.m. How many teeth does the gear on the shaft have?

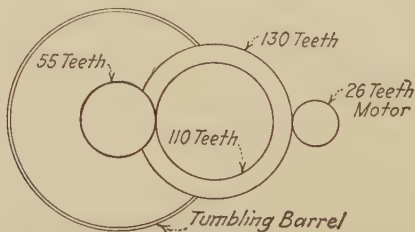


FIG. 42.

4. A tumbling barrel must make 40 r.p.m. to clean the castings. The gears are meshed as in Fig. 42. How many revolutions of the motor are necessary?

5. Suppose the motor speed is 1,500 r.p.m. What is the r.p.m. of the tumbling barrel?

Topical Question

1. Which are more practical in the cleaning room (a) belt-driven tumbling barrels or (b) direct drives? Why?

Text Reference

1. HIGGINS, LOTHROP D., "Introductory Physics," pp. 145-146.

CHAPTER XXXIII

INCLINED PLANE, WEDGE, AND SCREW

Moving a barrel or other object up a sloping runway instead of lifting it directly is a familiar thing in the foundry as in other places where heavy objects are moved. The track from which cars feed the hopper of a blast furnace is usually on a slope. Both are examples of the inclined plane. The screw and wedge are special forms of the inclined plane. The purpose of the plane is to move a heavy weight with a small force.

Any roadway or railway ascending a hill or rise of ground may be regarded as an inclined plane. The slope of such roadways is referred to as the "grade" and is generally

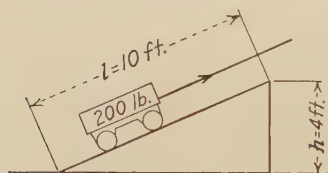


FIG. 43.

expressed as a ratio or as a percentage. Thus a 1:20 grade is a grade in which the vertical rise is 1 unit for 20 units along the horizontal. Such a grade might also be called a 5 per cent grade, the rise being 5 per cent of the horizontal advance.

In Fig. 43, if the car is lifted through the height h , the work done is $W \times h$. If it is pulled up the plane, the work done is $P \times l$. Since the work done is the same in either case

$$W \times h = P \times l$$

In the example in Fig. 43, $200 \times 4 = P \times 10$, or $P = 80$ lb. Therefore, a force of only 80 lb. is necessary to pull the car up.

The above equation may be written as a ratio $\frac{W}{P} = \frac{l}{h}$.

It is seen in Fig. 44, that when the wedge is driven forward the length l , the weight is lifted a height h . Using the ratio

$$\frac{W}{P} = \frac{l}{h}, \text{ in Fig. 44, } \frac{1,000}{P} = \frac{10}{1} \text{ or } P = 100 \text{ lb.}$$

The comparison of $1/h$ is the mechanical advantage of the plane. In the first figure, the *M.A.* is $10/4$; in the second, it is $10/1$.

The screw is nothing more than a spiral plane (Fig. 45). The thread is an inclined plane running around the rod. Turning the screw gives the same effect as pushing on an inclined plane. One revolution of the screw moves the body of the screw vertically through the distance between two teeth. This distance is called the pitch of the screw. If the pitch is 4, then 4 revolutions will move the screw 1 in.

Here, again, the equation of work is used. A force F on the handle (Fig. 45) moves through one revolution, and the work done is $2\pi l \times F$ where $2\pi l$ is the circumference of

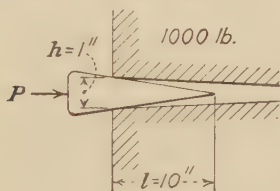


FIG. 44.

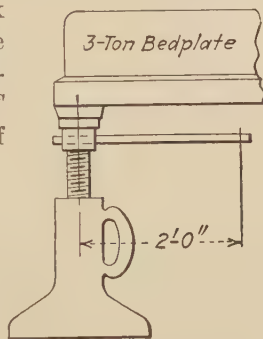


FIG. 45.

the handle circle. The weight is raised a distance h , so that the work done is $W \times h$. Since these two are the same

$$2\pi l \times F = W \times h$$

Caution must be exercised in keeping the units used the same. The distance must all be in feet, or inches, or in whatever other unit is used.

In dealing with the inclined plane, especially in such cases as the sloping skidway, the wedge, or the screw, friction is a very important consideration. This subject is dealt with in detail in the chapters on friction and efficiency, to which reference should be made. The theoretical mechanical advantage is never attained in any mechanism because of the power wasted in this manner.

Problems

1. Suppose that a 3-ton bed plate is to be leveled by the use of two jack screws. The length of the handle is 2 ft. and the pitch is 8. What force is necessary? (Fig. 45.)

2. Two blocks, one resting on the other, are to be separated with a wedge. The top block is to be raised 1 in. as the wedge moves in 10 in., and the block weighs 1,000 lb. What force must be used on the wedge? (Fig. 44.)

3. The buckets carrying fuel, ore and limestone to the top of a blast furnace weigh 29,000 lb. when loaded. The hopper is 150 ft. above ground, while the tracks are 200 ft. long. What pull is required on the buckets? (Fig. 43.)

4. A wedge 8 in. by 1 in. is to raise a 2-ton bed plate (Fig. 46). What driving force is necessary?

5. If in Fig. 45, a force of 150 lb. is exerted on the handle, what weight can be raised?

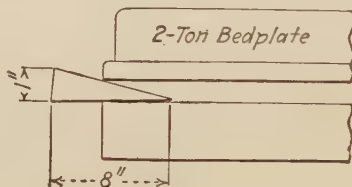


FIG. 46.

6. If in Fig. 43, the pull is 100 lb., what weight can be moved up the plane?

Topical Questions

1. Explain how a large cope is often started off by the use of wedges. Why is this done?

2. Give an example of how the inclined plane is sometimes used in taking charges to the charging floor from the yard. Do you consider this an economical method?

Text References

1. HIGGINS, LOTHROP D., "Introductory Physics," pp. 146-148.
2. SEARS, FREDERICK E., "Physics for Secondary Schools," pp. 2, 13, 174-186.

PART VI
MECHANICS OF FLUIDS

CHAPTER XXXIV

TRANSMISSION OF PRESSURE BY FLUIDS

It is a fortunate fact for industry that fluids, including gases as well as liquids, when subjected to pressure, transmit pressure equally in all directions. The principles which govern liquid pressure were discovered nearly three centuries ago by a scientist named Pascal and are embodied in the following statement known as *Pascal's law*: A pressure which is applied to any portion of the surface of a liquid is transmitted in all directions and is exerted unchanged in amount upon every equal portion of the surface of the containing vessel at right angles to that surface.

It is due to this fact that we can utilize the power of steam, compressed air, and water pressure.

In a water cylinder fitted with a piston carrying a weight, W , as shown in Fig. 47, the weight is carried equally by every drop of the water. If the weight amounts to 30 lb. for every square inch of piston area, then every square inch of surface in contact with the water will be subjected to 30 lb. pressure.



FIG. 47

If the piston were 8 in. in diameter and the weight were 5,026 lb. the pressure per square inch would be calculated as follows:

$$\text{Area of piston} = 8 \times 8 \times 0.7854 = 50.26 \text{ sq. in.}$$

$$\text{Total pressure on piston} = 5,026 \text{ lb.}$$

$$\text{Pressure per square inch} = \frac{5026}{50.26} = 100 \text{ lb.}$$

In Fig. 48, there are two different sized pistons connected by a passageway for the water.

Suppose the force P is 150 lb. Then:

$$\text{Total pressure on small piston} = 150 \text{ lb.}$$

$$\text{Pressure per square inch} = \frac{150}{1} \times 1 \times 0.7854 = \frac{150}{0.7854}$$

$$\text{Pressure per square inch on large piston} = \frac{150}{0.7854}$$

$$\text{Total pressure on large piston} = \frac{150}{0.7854} \times 12 \times 12 \times 0.7854 = 21,600 \text{ lb.}$$

Thus, it is seen that a pressure of 150 lb. is made to exert a pressure of 21,600 lb. by means of the arrangement shown in Fig. 48. This is possible because liquids transmit pressure equally in all directions.

The work done on the small piston, however, must equal the work obtained from the large one. Suppose the small piston moves 6 in. The work done is $6 \times 150 = 900$ lb-in. The work obtained from the large piston is $21,600 \times h$ where h is the distance moved.

$$\text{Since } 21,600 \times h = 6 \times 150, h = \frac{1}{24} \text{ in.}$$

Hence, it is seen that although a greater force is exerted by the large piston, it moves a less distance or more slowly than the small piston.

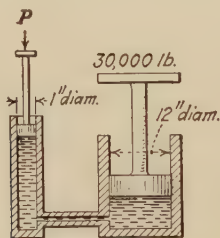


FIG. 48.

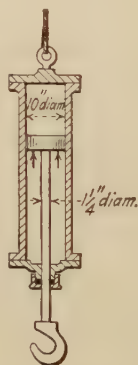


FIG. 49.

Problems

1. In Fig. 48, what is the value of P ?
2. Suppose P were 250 lb., what weight could be lifted?
3. If P were 200 lb., the weight to be lifted, 8 tons, and the diameter of the large piston 10 in., what would be the diameter of the small piston?
4. Figure 49 shows an air hoist. With the dimensions shown and a pressure of 80 lb. per square inch, what weight can be lifted? The pressure is on the bottom.

5. If the weight to be lifted were a 3-ton casting, what would be the diameter of cylinder, other things being the same?

Topical Questions

1. What is the relative effect upon the possibility of decreasing shrinkage of (a) increasing the height of risers; (b) increasing the diameter of risers?

2. What practical result in addition to the possible effect on shrinkage must be considered in increasing the height and diameter of risers?

3. How can a knowledge of ferrostatic pressure reduce the amount of scrap in a foundry?

4. What precautions must be taken against the laws of ferrostatic pressure of molten metal in (a) setting and securing of cores; (b) in making of cores?

5. If a foundryman should attempt to get additional pressure over a spongy portion by increasing the diameter of sprues, what would be the result? Why?

Text References

1. HIGGINS, LOTHROP D., "Introductory Physics," Chap. III.
2. SEARS, FREDERICK E., "Physics for Secondary Schools," Chap. IV.

CHAPTER XXXV

THE HYDRAULIC PRESS

The fact that fluid pressure affords an almost perfect means of transmitting power over short distances has led to the extensive use of hydraulic machinery using water chiefly as a medium, and to the use of pneumatic machinery using air. Molding machines, presses, punches, shears, and many other sorts of machinery are operated by hydraulic and pneumatic power. Where enormous pressures are required, water is usually used, since it is nearly incompressible and is easily obtained. Oil instead of water is used in a few instances in small apparatus. The use of compressed air for operating molding machines, rammers, chipping hammers, hoists, and other apparatus is quite general and is familiar to everyone in this branch of industry.

The principle of the hydraulic press has already been touched upon but a more complete diagrammatic view of such a press is shown in Fig. 50. No attempt has been made to do more than show the principle of operation. Many important details are not shown; for example, the method of releasing the ram, which is accomplished by means of a rather complicated three way operating valve which is thrown by hand. This valve could not be shown in detail here, and mere diagrams of the two check valves are given. The pump also is hand operated in only the very smallest machines, such, for example, as are used in certain testing apparatus. In most cases, it is motor operated; or in some very large presses the small plunger is actuated by direct steam pressure.

Referring to Fig. 50, both cylinders, the pipe system, and the tank are assumed to be already filled with water and brought to the position shown with the plunger in the small cylinder beginning a down stroke. As the small piston

descends, Valve *M* drops, preventing the water from going back to the tank, and Valve *N* opens, admitting water to the large cylinder. When the small piston begins its upward stroke, Valve *N* closes by gravity, and the external air pressure on the surface of the water in the tank forces Valve *M* open, admitting water into the pipes back of Valve *N*. Assume a diameter of 2 in. for the small cylinder and 8 in. for the large one, and the areas of the pistons will be as 2^2 to 8^2 or as 1:16. It is apparent that, by Pascal's Law, a pressure

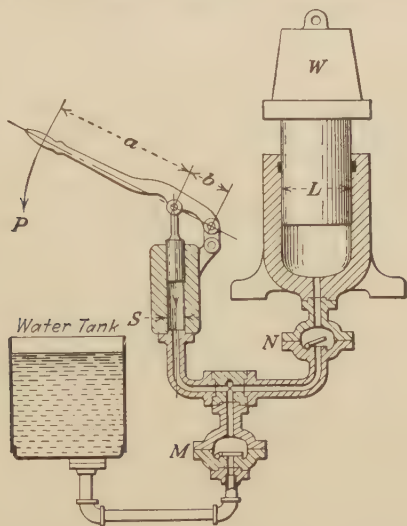


FIG. 50.—Diagrammatic sketch of hydraulic press.

of 100 lb. applied to the small piston will produce a pressure of 16×100 lb. or 1,600 lb. on the large piston. The mechanical advantage of the press is 16:1 for the hydraulic system. In addition there is also the M.A. of the handle lever.

If it is assumed that $a = 15$ in. and $b = 5$ in. then the M.A. of the lever is $(15 + 5):5$ or 4:1. A force, P , amounting to 25 lb. would thus suffice to produce the 100 lb. pressure on the small piston and the 1,600 lb. on the large piston referred to above. The total M.A., then, of the entire machine, disregarding friction would be $(4:1) \times (16:1) =$

$$\frac{4}{1} \times \frac{16}{1} = 64.$$

In a former chapter it has been learned that $\text{Work} = \text{Force} \times \text{distance}$. Since the rising of the large piston is the effect of the energy transmitted from the small cylinder, the work done on the small cylinder must be equal to that done on the large. Then if the force applied to the large cylinder be 16 times as great as that on the small cylinder, the small piston must move 16 times as fast as the large one.

Problems

1. A hydraulic press operates under a pressure of 1,500 lb. per square inch. What must be the diameter of the large piston to raise a casting weighing 75,000 lb.?
2. Two hydraulic jacks are used to level a casting. The diameters of the large and small pistons are 4 in. and 1 in. respectively. What force is required in the small piston to raise the casting if the weight is 4 tons?
3. If the diameters of the large and small pistons are 2 ft. and 4 in. respectively, what force is necessary to lift 6 tons?
4. In Problem 3, what weight will a force of 250 lb. lift?
5. In Fig. 50, let the small cylinder be 1 in. in diameter, and the large one 12 in. in diameter. The small cylinder has a 6-in. stroke and makes 60 strokes per minute. At what rate does the large piston rise?
6. What is the mechanical advantage of the water system in Problem 5?

References

1. See references given in first chapter of this Part.

CHAPTER XXXVI

PNEUMATIC TOOLS AND EQUIPMENT

Some of the light machines in the foundry, such as the chipping hammers, molding machines, and hoists, are operated by air. Air is preferred to water in these cases, because it can be let in or out of a cylinder very quickly, thus allowing higher speeds. The principle of pneumatic or air tools is the same as that of hydraulic apparatus. The air is subjected to pressure which is transmitted equally throughout.

In the illustration in Fig. 51, air is supplied to the piston through a pipe. This air has been forced in under great pressure so that it pushes back with a pressure of 80 lb. per square inch. The total force exerted by the air is:

Pressure per square inch = 80 lb.

Total area = $10 \times 10 \times 0.7854 = 78.54$

sq. in.

Total pressure = $78.54 \times 80 = 6,283$ lb.

The air required is taken from the atmosphere and compressed into a tank. As more and more air is forced into the tank, the pressure rises until it reaches the number of pounds desired per square inch. The air is then conveyed to a piston through a pipe or hose. Since fluids transmit pressure equally, the pressure at the end of the pipe is the same as the pressure in the air tank.

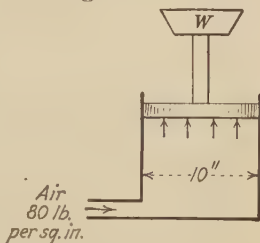


FIG. 51.

Problems

1. If the diameter of the piston is 2 in., and the pressure of the air is 80 lb. per square inch, what force is exerted?
2. A molding machine operates under a pressure of 85 lb. per square inch. If the diameter of the piston is 5 in., what force is exerted?
3. What air pressure would be required in the above problem to exert a pressure of 2,000 lb.?

4. A molding machine is operated with two 4-in. pistons. What air pressure is necessary in order that the machine may exert a force of 2,500 lb.?

Topical Questions

1. What is the usual air pressure carried in foundries where there are a great many machines operated by air?

2. What difficulty do some foundries have with compressed air in the winter? How can this be practically eliminated?

3. Explain how vibrators accomplish the separating of the sand in the mold from the pattern plate.

4. Modern squeezer machines have an automatic shut off installed on their line which can be set for any pressure. Do you believe these are important? Explain.

5. What is the most expensive power medium used in foundries?

6. In a certain plant, 2 steam hammers were placed at one end of the blacksmith shop adjoining the large foundry. What effects would you expect these hammers to have had in the foundry? Explain briefly in detail.

References

1. See references given in the first chapter of this Part.

CHAPTER XXXVII

STEAM

Steam is another fluid which is made to do work in exactly the same manner as water and air. Steam is used where high pressure and quick operation are desired. Most heavy machinery is operated by steam. Being a gas, steam is very elastic and this property is utilized to attain suitable pressures for operating engines.

The pressure of steam is obtained by boiling water. As the liquid changes to gas, it expands to 1,600 times its original volume. Steam, as it is formed, is the same temperature as the water from which it comes. The heat which is absorbed during this vaporizing process has become latent or hidden. The steam is confined in a boiler; and as more steam is produced, the pressure inside the boiler increases. In this way, the pressure per square inch can be raised to whatever amount is desired and which the boiler is able to stand. The intense pressure of steam is the result of confining in a small space a gas, the particles of which have a very great movement.

The steam is conveyed to a piston by means of a pipe. Since the pressure of a fluid is transmitted equally, the steam has the same pressure at the end of the pipe as it has in the boiler.

Example.—Steam is supplied at 200 lb. per square inch to a piston 10 in. in diameter. What weight can be lifted?

Pressure per square inch = 200 lb.

Total area = $10 \times 10 \times 0.7854 = 78.54$ sq. in.

Total pressure = $78.54 \times 200 = 15,708$ lb.

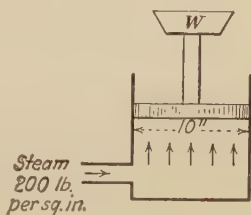


FIG. 52.

Problems

1. A steam hammer has a piston diameter of 9 in. The steam supplied has a pressure of 120 lb. per square inch. What is the force of the blow?

2. An automatic feed for a furnace is operated by steam. The force necessary is 1,820 lb. If the diameter of the piston is 8 in., what steam pressure is required?

3. A small engine is used about the shop for moving cars. It has a pressure of 80 lb. per square inch, and a piston diameter of 13 in. What pull can it exert?

4. A steam hammer must have a blow of 2,900 lb. The diameter of the piston is 10 in. what steam pressure is needed?

Topical Questions

1. Explain how a single small potato on a forked iron rod held for a minute at the bottom of the ladle can stir 5 tons of metal. McWilliam and Longmuir in "General Foundry Practice," 3d Ed., revised 1920, mention this being done when molten copper has been collected in a ladle, the amounts of zinc and tin necessary for the alloy added and thorough mixing is desired.

2. Too hard spots on the surface of a mold may lead to the formation of scabs. What is the force involved and how can it be controlled so as not to cause damage?

3. What other condition of the sand than that resulting from too hard ramming will produce blow holes? Why does this happen?

Text References

1. HIGGINS, LOTHROP D., "Introductory Physics," pp. 169-179.

2. SEARS, FREDERICK E., "Physics for Secondary Schools," pp. 9, 287-288, and Chap. XV.

PART VII
EFFECTS OF ELEMENTS ON IRON

CHAPTER XXXVIII

CARBON AND ITS EFFECT ON IRON

Pure iron, like pure gold, is so soft that it can easily be marked by the finger nail. Iron and gold would be of comparatively little industrial or commercial use if this quality of softness could not be changed.

The properties of metals, however, can be greatly changed by alloying them with other substances. Carbon is one of the substances which affects the properties of iron. As Moldenke points out, the whole superstructure of the iron industries rests on the important compounds of iron with carbon and, to a less extent, on the compounds with other elements.

Iron, at the utmost, can hold in solution about 4.0 to 4.6 per cent of carbon, the amount varying according to different authorities. The exact amount and form of these small percentages of carbon are of great importance.

The dividing line between steel and cast iron is 2.00 per cent carbon. High carbon steel contains less carbon than low carbon cast iron. The harder tool steels and the mild steels are sometimes referred to as carbon steels. This is because other classes of steel contain less carbon than the carbon steels and also small amounts of nickel, manganese, chromium or other elements which give certain desired qualities to the alloys. Carbon is an essential element in all these alloys.

The percentage of carbon in gray cast iron averages around 3.5 but this is only half the story as far as it concerns the qualities of the castings. The form of the carbon is as important as its total amount.

The molten iron in the cupola holds many materials in solution just as hot water dissolves or brings into solution larger quantities of sugar or other substances than are dissolved

in cold water. Cold iron, like cold water, is not as powerful a solvent as the heated liquid. Sugar is commonly observed in the bottom of a pitcher or can which has been filled with hot syrup, that is, a hot sugar solution. When the solution cools, the lowered solvent power has led to a part of the sugar separating out.

The changes in composition of cast iron which take place during its solidification are very complex, and are not thoroughly understood at the present time. The portion of the mass which solidifies last is called the eutectic.

The uncombined carbon is graphite or graphitic carbon. It is the same substance as the lead in pencils. The flakes of black graphitic carbon are plainly visible in a photomicrograph of a section of cast iron. The presence of graphitic carbon, as would be expected, weakens a casting and softens it.

The carbon which is not thrown out of solution during cooling is called combined carbon. Combined carbon increases the hardness of cast iron.

Moldenke, on page 65 of the "Principles of Iron Founding," reports an experiment of adding varying amounts of aluminum to ladles of white iron. The amounts of aluminum added ranged from 0.1 to 1 per cent by one-tenth per cent increases. That is, to the different ladles aluminum was added to the extent of 0.1 or 0.2 or 0.3 per cent and so on. The proportion of graphite and combined carbon in the iron from the various ladles ranged from 0.08 per cent graphite and 2.74 per cent combined carbon to 2.01 per cent graphite and 0.78 per cent combined carbon. The iron from the first two tests was, of course, the highest in combined carbon and was so hard that it "could not be touched with the drill."

The beginning student should not think that the occurrence of carbon in iron is as simple as the proportion of combined and graphitic carbon. A brief glance at a description of the eutectic mixture of iron carbide and iron, sometimes called pearlite, will convince him of the complexity as well as the importance of this problem. The understanding of a few fairly well established facts will help to prepare the student for a later consideration of the more complicated problems on which there are many differences of opinion.

Since carbon in these two forms, graphitic and combined, has exactly opposite effects upon the qualities of castings, it is important to recognize these effects and to understand some of the conditions under which the desired amount of carbon is held in solution or is thrown out as graphite.

The proportion of combined and graphitic carbon depends upon at least four factors: (1) the rate of cooling; (2) the composition of the mixture particularly as to silicon; (3) the total carbon present; (4) the temperature of the iron when it begins to cool, and the temperature and duration of superheating if this has occurred.

The more quickly iron is brought below the freezing temperature, the more carbon is held in the combined state. During slow cooling, more of the carbon separates out as graphite.

Silicon decreases the combined carbon and increases the graphite. A high percentage of sulphur or manganese possibly tends indirectly to have exactly the opposite effect, that is, increase the proportion of combined carbon in the iron.

The greater the amount of total carbon present, the greater the proportion of graphitic carbon to combined carbon. And finally, the higher the temperature at which iron begins to cool and the greater superheating of the iron both as to temperature and duration, the greater the proportion of graphitic carbon. Lower carbon in cast iron means stronger and denser castings.

In melting, there is sometimes a loss of carbon but generally the iron gains in carbon by picking up some from the coke.

The varying effects of silicon, sulphur, and manganese on the amount of carbon held in solution show how complex are the changes which take place in the cupola. These changes will be better understood after reading the chapters on the effects of other elements upon iron.

The effect of manganese upon cast iron is an example of how the different elements influence each other in the formation of compounds and alloys, and thus influence the qualities of the finished castings. Manganese alloys with iron in every proportion, but this tendency of manganese to form an alloy with iron is not as strong as its tendency to form a

chemical combination with oxygen, or carbon, or sulphur. Iron also has a strong attraction for oxygen, carbon, and sulphur. The affinity of manganese for carbon is stronger than that of iron. An iron-manganese carbide $((\text{FeMn})_3\text{C})$ occurs in cast iron; and high manganese pig iron as well as ferromanganese alloys contains a high percentage of carbon. Manganese is stronger than iron in the chemical affinity for sulphur, hence the manganese sulphur ratio is of importance in protecting iron from the possible bad effects of sulphur. These complex chemical attractions and tendencies to form alloys account for some of the apparent inconsistencies in the effects of manganese in mixtures.

Four terms sometimes used in the discussion of the metallurgy of cast iron are cementite, ferrite, pearlite, and austenite. A brief comment on each may be helpful to the reader.

1. *Cementite*.—A chemical compound of iron and carbon usually containing manganese. Tensile strength 5,000 lb. per square inch, very hard and brittle, 6.68 per cent carbon.

2. *Ferrite*.—Iron containing no carbon, and small amounts of silicon and phosphorus. Tensile strength 50,000 lb. per square inch, very ductile.

3. *Pearlite*.—Alternate layers of ferrite and cementite. Under microscope, looks like mother of pearl. Contains 0.83 per cent carbon. Tensile strength 125,000 lb. per square inch.

4. *Austenite*.—A solid containing various proportions of cementite and ferrite. Carbon content from 0 to 1.7 per cent. If iron is slowly cooled, austenite is not found below a temperature of 1292°F . Transition forms between austenite on the one hand, and ferrite and cementite on the other, in varying proportions, are named *martensite*, *troostite* and *sorbite*.

No one fully understands the complex physical and chemical changes that take place when many elements and compounds are brought together at the high temperatures of the cupola. It has been truly said that a foundry is a practical metallurgical laboratory.

The foundry is only one of the places where carbon plays a large part in modern industrial life. In a vocational

chemistry used in many high schools, a summary is given of 31 of the important forms of carbon and compounds of carbon and their uses. Cast iron is not mentioned in this list although coke and carborundum are. The chemistry of carbon is sometimes called the chemistry of life. An understanding of the part which carbon plays in a few of its forms and compounds is an introduction to one of the many phases of modern industrial life.

Topical Questions

1. In outline form, show the effect of graphitic and combined carbon upon the qualities of cast iron. Use only one word "increases" or "decreases" unless more terms are necessary.

2. What percentage of carbon is considered a large amount in steel? In gray cast iron? In malleable iron? In white cast iron? What percentage might be found in a low carbon steel? A low carbon gray cast iron?

3. What are two reasons for the increase of the amount of graphitic carbon in castings of iron which has been superheated in the cupola?

4. In machining gray cast iron is it necessary to apply oil or other lubricant? Why?

5. What is the most important reason why gray cast iron is weaker than steel?

6. What effect does the use of steel scrap in place of agricultural machinery scrap have upon the carbon content of cast-iron products? Why?

7. What is the effect upon the total carbon of adding ferromanganese to a ladle? Explain.

8. How does the addition of ferromanganese to the ladle affect the properties of the castings?

9. How is the carbon content of cast iron affected by the oxidation of iron?

10. What three difficulties related to carbon may result from oxygen in molten iron?

11. Where are the lubricating qualities of graphite made use of in the treatment of cast iron?

12. How does the composition of white cast iron account for its color?

13. (a) What is the peculiar cooling characteristic of white cast iron? What is the relative amount of silicon in white cast iron? (b) How do these two factors affect its composition and color?

14. If a file will not bite into a casting, what kind of a mixture may have been used? Explain.

15. Are high silicon irons usually hard or soft? Why?

16. Why does the addition of steel scrap reduce the total carbon content of castings?

17. Since carbon is so important in cast iron, why is it not calculated in the making of a mixture as silicon and some other elements are calculated?

18. What change in composition and properties results from carburizing when pieces of low carbon steel are packed in charcoal or bone ash and held for several hours at a high temperature? (See p. 177, "The A B C of Iron and Steel.")

19. Mention two observations or experiences of your own which have been explained by this chapter.

Text References

1. MOLDENKE, RICHARD, "Principles of Iron Founding," pp. 38-42, 44, 50, 65-66, 129-130, 309, 443-444.
2. SPRING, LAVERNE W., "Non-technical Chats on Iron and Steel," 2d. Ed., 1927, pp. 8, 74-90, 106-117, 180-184, 198, 233.
3. Specifications, Nos. 140, "Gray Iron Castings" and 141, "High Test Gray Iron Castings"—Federal Specifications Board, U. S. Dept. of Comm.

Reading References

1. "The A B C of Iron and Steel," 5th. Ed., 1925, A. O. Backert, Editor, pp. 114, 177, 298.
2. Transactions of American Foundrymen's Association, Vol. XXXIV, 1926, pp. 697-702, 844-848.
3. WILLAMAN, JOHN J., "Vocational Chemistry," "Carbon," Chap. VI, especially p. 80, "Summary of the Chemistry of Carbon."

CHAPTER XXXIX

SILICON AND ITS EFFECT ON IRON

Silicon and silica are two familiar words in a foundry. One refers to an element of which the exact amount in the mixture greatly affects the qualities of castings. The other is the name of a compound in which this element has acquired characteristics differing from those of the element, much as oxygen has lost its identity in the compound, water.

Silicon is found in nature only in combination with other elements. The compounds of silicon with oxygen known as silica and silicates are the most common forms. Fire clay and fire brick are composed largely of silica and owe much of their heat resistance to this substance.

The element, silicon, in the cupola charge is calculated as coming from pig iron, scrap, and ferrosilicon or other compounds high in silicon. The percentage of silicon determines the grade of foundry pig iron. The Federal Specifications Board, in 1924, set the following requirements:

Grade of Foundry Pig Iron	Silicon, Per Cent
No. 1.....	2.75 to 3.25
No. 2.....	2.25 to 2.75
No. 3.....	1.75 to 2.25
No. 4.....	1.25 to 1.75

In purchasing pig iron, a variation of ± 0.25 per cent in silicon is allowed, that is, 0.25 per cent above or below the amount stated, is binding. Hundredths of a per cent are most commonly referred to as "points." A variation in silicon within 25 points is allowed. If a contract called for 1.75 per cent silicon, any amount of silicon between 1.50 and 2.00 per cent would be allowable unless a narrower variation were stipulated.

The amount of silicon in the pig iron is the basis of the price of the pig iron. Thus No. 1 pig iron costs more than No. 3 pig iron, due to the difference in silicon content. For this reason, many foundries are using No. 2 pig iron where they formerly used No. 1 iron. This is the case in stove plate shops and light-gray iron foundries. They are saving approximately 50 cts. a ton on pig iron and yet getting satisfactory results with a 2.00 to 2.25 silicon and a high phosphorus. The phosphorus imparts the necessary fluidity to the iron, increased fluidity being one of the effects of silicon.

The fracture test of pig iron is an unsatisfactory indication of the silicon content. The high silicon irons, that is, the better grades, were supposed to have an open grain. So many factors influence the grain that it is possible to have two samples of apparently equal closeness of grain, one low in silicon and one high. By modifying the rate of cooling, metal with 1 per cent silicon may show a more open grain than another with 2.5 per cent. For these reasons, the grade of foundry pig iron is today generally determined by chemical analysis.

Ferrosilicon may contain up to 50 per cent or even more of silicon, depending on the method of manufacture. The electric furnace is necessary for any percentage above 20. Ferrosilicon is added to the charge or to the ladle in order to bring up the percentage of silicon in the castings. This practice introduces a number of problems and is justifiable only when the foundry does not have iron of the proper silicon content to obtain the required analysis.

Silicon is easily oxidized and the high temperature of the cupola leads to a loss of silicon by oxidation. This loss varies according to the amount of silicon and the methods of operating the cupola. In calculating the mixture, an allowance of 0.25 per cent of the mixture, or 25 points, is usually made for this loss.

Silicon is valuable in the cupola as a deoxidizing agent, though for this purpose it ranks below manganese, aluminum, and titanium. The difficulties arising from oxidized iron in the molten metal have been considered previously. Here, as elsewhere, prevention, when possible, is more economical than treatment.

Silicon is known as a "softener" in the foundry. In amounts up to 3.5 or 4 per cent, it reduces the hardness and, therefore, increases the machinability of castings. Above 3.5 or 4 per cent, the presence of silicon may have the effect of hardening the castings.

In itself, silicon is not a softener. As was explained in the preceding chapter, the effect of silicon upon the hardness of iron is the result of its action in reducing the amount of combined carbon and increasing the graphitic carbon. Silicon may be thought of as competing with carbon for a combination with iron, and it is stronger than the carbon.

The result is that as the percentage of silicon increases, less carbon remains in combination with the iron. The carbon, which is thrown out of combination, appears as graphitic carbon. Graphite softens and weakens irons. This softening is indirectly the effect of silicon.

It has been emphasized that the effect of silicon in softening iron continues progressively up to a certain point, about 3.5 or 4 per cent of silicon. Very high silicon castings, those having 12 to 15 per cent or more, are used where acid resisting metals are needed. This metal is very hard, but its strength is low (Moldenke, pp. 170-172). This metal is of interest to the foundryman producing castings with silicon below 3.5 per cent only as illustrating the fact that there is a limit to the softening effects of increased silicon.

Conversely, the low silicon cast irons contain high combined carbon and tend to be hard and strong. As would be expected, white cast iron and chilled castings are low in silicon. The content of silicon, it must be remembered, is only one of the factors which determine the relative amounts of graphite and combined carbon in castings. Another factor is the rate of cooling. Slow cooling allows time for the carbon to separate out in large black flakes which act as a lubricant when the castings are drilled. The rate of cooling is different for large and small section castings, and so in order to get large section castings with the desired amount of combined carbon, the percentage of silicon is kept low.

Slow cooling and high silicon tend to reduce the amount of combined carbon and thus produce castings which can

be machined easily. It should be remembered that the softness which produces machinability is due very largely to the presence of graphite.

So many factors determine the qualities of castings that it is not surprising to find hard castings sometimes produced when the silicon is high. An examination of the cupola practice in these cases may reveal conditions producing quicker setting of the metal than usual. The iron may have been melted cold or damp molds may have been used. Castings may have been shaken out too soon, allowing them to cool too quickly, thus holding more of the carbon in combination.

Occasionally, hard castings may be produced with silicon as high as 3.25 per cent when there has been no change in the cupola practice. An increase in the manganese and sulphur will produce this result even with a large amount of silicon.

This brief review of the place of silicon in the casting of iron, suggests a reason for the advantages claimed, in certain kinds of work, for the use of heated molds in connection with low silicon irons. The heating of the molds retards the cooling which, otherwise, would tend to be fairly rapid with the low silicon.

While silicon in the past has been depended upon to give certain desirable qualities to cast iron, investigation and modified foundry practices are showing that lower silicon can be used with small percentages of nickel, vanadium, molybdenum, or other elements. Investigations such as these are watched with interest by the foundry man who realizes how greatly a small change in mixture or methods of cupola control may influence costs and quality.

Silicon, next to carbon, is the most important element in its effect upon the qualities of cast iron. It is usually the first element considered in calculating a charge. Its effects are intimately associated with the proportions of other elements, and with the details of the operation of the cupola.

Topical Questions

1. (a) Arrange the following elements in the order of their uniting with oxygen at high temperatures: iron, silicon, carbon, manganese. Connect by a brace any two or more of these elements that are about equal in

their respect. (b) What is one value in the foundry of the two elements you placed first in the previous question?

2. (a) A contract calling for 3 per cent silicon in foundry pig iron can be filled by what upper and lower limits, according to the United States Specifications Board? (b) What color is an iron containing 0.4 per cent of silicon apt to be? Why?

3. Where would you look for the source of the trouble if all of the castings were giving difficulty in machining because of fairly uniform hardness? If only a few castings in each lot were too hard to machine easily?

4. While silicon is usually considered to weaken as well as to soften iron, under what conditions may the addition of extra silicon increase the strength? Explain.

5. Which irons are more susceptible to oxidation, those with high silicon or those with low silicon? Why?

6. Which is needed, a relatively high or a relatively low percentage of silicon when: (a) Valves and fittings are to be cast? (b) Iron molds are substituted for sand molds and the same machinability is desired as before? (c) Heavy section castings are to be made?

7. Which should silicon be, high or low, if the same mixture is to give a very light chill with iron molds and a gray fracture when poured into sand?

8. What is the main feature in the composition of chilled iron? What conditions are necessary for the production of a chill? How does silicon affect the production of a chill?

9. Through what two changes in the composition of cast iron does silicon exert its softening effect?

10. How does steel scrap affect the qualities of iron castings, directly or indirectly? Explain briefly. (Spring, p. 186.)

11. Since iron in the cupola is in contact with coke, how can the presence of silicon in iron affect the *total* carbon present in castings? In other words, although silicon's strong attraction for iron can reduce the combined carbon present, does this element affect the total amount of carbon the iron carries out of the cupola?

12. How do you account for the fact that a small test bar may contain 0.75 per cent combined carbon and a 2-ton casting from the same ladle may contain only 0.25 per cent combined carbon?

13. As the size of the sections of castings increases, which is needed, more silicon or less? Why?

14. In the mixture for machinable castings $\frac{1}{2}$ in. thick which must show no tendency to chill at the sharp corners of the thin sections which is needed, a comparatively high or low silicon? Why?

15. What precaution must be observed in regard to the silicon content when domestic scrap in large amounts is continually used? Why?

16. Mention three or more conditions in the foundry which may produce harder castings than others produced from exactly the same mixture.

17. The element, silicon, is now produced in electric furnaces. If this 100 per cent silicon could be produced cheaply, would it be practical for the foundryman to use it in controlling the silicon content of his product? Why?

18. What is the range in the amount of silicon that may be lost in melting? What accounts for the upper and lower extremes? What is an average amount to add to the mixture to make up for this loss?

19. What content of silicon is calculated or approximated in gray iron scrap of different sizes of section?

20. Fill out the following table with the words "decrease" or "increase," using care to leave blank those spaces in which no definite influences can be recorded. Indicate your authority by page and book.

EFFECTS OF ELEMENTS ON CAST IRON

Elements	Melt- ing point	Fluid- ity	Contraction, shrinkage	Chill	Hard- ness	Strength	Porosity of grain
Silicon.....							
Combined carbon...							
Graphitic carbon....							

Review.—Underline all of the correct words or phrases and only those which are correct. "Other conditions being equal," is understood in all of the statements.

Example of How to Underline.—Increasing the combined carbon in iron (*a*) raises its melting point; (*b*) *lowers its melting point*; (*c*) increases its fluidity; (*d*) *makes it less fluid*; (*e*) decreases the chill; (*f*) *deepens the chill*; (*g*) softens the casting; (*h*) *increases the hardness*; (*i*) *increases the strength*; (*j*) weakens the casting.

The emphasis given to (*b*), (*d*), (*f*), (*h*), and (*i*) means that the person doing so believes that, other conditions being equal, increasing the combined carbon in iron lowers its melting point, makes it less fluid, deepens the chill, increases the hardness, and increases the strength.

1. 0.75 per cent silicon in cast iron is (*a*) low; (*b*) medium; (*c*) high. A fair amount of silicon in 1-in. section cast iron is (*d*) 2.0 per cent; (*e*) 1.0 per cent; (*f*) 3.0 per cent; (*g*) 2.5 per cent.

2. With lower silicon in iron (*a*) less carbon is thrown out in the combined form; (*b*) less carbon remains in the combined form; (*c*) more carbon is allowed to remain in the combined form; (*d*) more graphite is

formed during cooling; (e) less graphite is formed; (f) the chill is deepened; (g) the chill is decreased.

3. Increasing silicon in iron (a) increases the softness; (b) increases softness up to about 3.5 per cent of silicon; (c) makes it less fluid; (d) increases fluidity; (e) prolongs the life; (f) strengthens the castings; (g) weakens the castings.

4. A heat of iron with 1.07 silicon (a) would be protected from oxidation by the silicon; (b) be fairly susceptible to oxidation; (c) be very susceptible to oxidation; (d) be used in making stove plate; (e) be used in making heavy section castings; (f) tend to be very fluid; (g) not tend to be very fluid.

Text References

These references may repeat material which has been assigned before and which the student may need only to review briefly. Only the part of a page is intended which refers to the subject of the chapter.

1. MOLDENKE, RICHARD, "Principles of Iron Founding," pp. 41-44, 54, 101, 121-128, 156, 170, 216, 224-225, 236, 238-239, 325, 410-411, 441.

2. SPRING, LAVERNE W., "Non-technical Chats on Iron and Steel," 2d. Ed., 1927, pp. 83, 86, 120-133, 167-168, 178-186, 346-349.

3. Specification No. 126a, "Foundry Pig Iron," March 1928, Federal Specifications Board, U. S. Dept. of Comm.

CHAPTER XL

MANGANESE AND ITS EFFECT ON IRON

The element, *manganese*, does not occur free in nature. It occurs commonly in combination with oxygen and iron in iron ores. Practically all iron ores contain manganese, and the percentage in the ore determines the percentage in the pig iron.

The foundryman obtains manganese in pig iron and in alloys with iron. The manganese in pig iron varies from 0.20 to 4 per cent. In specifying this element in purchases, in which a tolerance or variation of 0.20 (20 points) either way is allowed, the percentage called for should be sufficiently high to insure at least 0.50 manganese in the castings. In regions of low-manganese ores and pig irons, the deficiency can be made up by ferromanganese additions.

Ferromanganese is an alloy, the standard grade of which contains 80 per cent manganese. It is purchased in the lump form for use in the cupola and in the powdered form for addition to the ladle or for use in case hardening.

Silicospiegel is an alloy of iron, silicon, and manganese. It is used sometimes in the foundry when an addition of both silicon and manganese is desired.

Although the percentage of manganese in castings can be controlled by the addition of certain alloys to the cupola or ladle, it is considered better practice to control this element through the use of pig iron which will give the desired amount. Manganese steel scrap containing about 12 per cent manganese is sometimes used to correct the pig iron.

The melting loss of manganese varies greatly. A loss of 20 per cent is usually calculated in producing castings with any certain amount of manganese. When powdered manganese alloy is added to the ladle, a large portion may be lost, partly because the heat is not great enough to bring it in

solution and partly because of its tendency to float on the surface.

The influence of manganese on iron castings depends on the amount of other elements and the time, temperature, and other factors in the operation of the cupola. These influences are quite complex; but the understanding of a few principles will help in gaining an understanding of some of the seemingly contradictory statements and results due to manganese.

The relative strength of the tendency of manganese to form alloys and chemical combinations will help to explain the part manganese plays in the production of castings of desired characteristics at moderate cost.

In discussing carbon, mention has been made of the tendency of manganese to alloy with iron in all proportions and of its strong chemical affinity for carbon.

Manganese has a tendency to carry carbon with itself into the iron alloy. High manganese pig iron and the ferro-manganese alloys have a comparatively high carbon content. If this greed for carbon has not been satisfied in a high manganese mixture, more carbon may be taken up in the cupola from the fuel. An addition of manganese even as late as in the ladle may result in a rise of carbon.

It will be remembered that carbon hardens or softens metal, depending upon whether the carbon is in the combined or graphite form, and also that the particular form of carbon depends in part on the amount of silicon. The lower the silicon, the more of the carbon is in the combined form and the harder the casting, other conditions being equal. As would be expected from this fact, if silicon is low (possibly 1 per cent) and manganese is high (1.5 per cent), there is a tendency for the castings to be hard, especially in the thinner sections. If, however, 0.6 to 1 per cent of manganese is present (an average amount), and the other elements are in proper proportion, the manganese tends to soften castings and to strengthen them.

In practice, manganese above 0.8 per cent has a tendency to overcome the action of silicon and thus to increase the combined carbon and harden the castings; so 0.7 is frequently considered an average desirable amount of manganese in

gray iron castings. This limit, however, is greatly influenced by the melting practices and the quantity of other elements needed to obtain certain desired qualities.

The iron-manganese carbide occurs in castings as globules or strings of fine grains. These produce very hard spots and give trouble in machining. This carbide is formed on the surface of a mold when powdered ferromanganese is used in case hardening.

The hardening of iron when manganese is used to deepen a chill may be due in part to another series of reactions. These involve the second important chemical attraction of the element manganese.

The strong chemical attraction between manganese and oxygen accounts for a number of the reactions of manganese in the foundry. This affinity is so strong that manganese acts as a deoxidizer in the molten metal. This element is sometimes spoken of as sacrificing itself and protecting carbon. In reality it simply is stronger than carbon in the effort to get available oxygen. Manganese is stronger in this respect than silicon and iron, and so helps to protect the mixture from the oxygen which these two substances may bring into it.

Although titanium and aluminum are stronger deoxidizers than manganese, the use of manganese is considered the cheapest method of freeing iron from oxygen and other injurious gases.

This deoxidizing power of manganese is made use of when the chill test shows that the chill is too deep. The deep chill means much combined carbon and usually low silicon. A very little powdered manganese in the ladle will delay the setting of the metal and thus make the chill lighter.

A regular manganese chill produced by the use of much ferromanganese in the cupola is considered undesirable (Moldenke, "Principles of Iron Founding," p. 124). Neither the hardness nor the strength of these castings is satisfactory.

The third principle governing the action of manganese in the cupola is the strong attraction between the manganese and sulphur, particularly at high temperatures. This is stronger than the affinity between manganese and iron. As

a consequence, manganese is sometimes found in cast iron in small particles of manganese sulphide. These hard spots give trouble in machining.

Manganese sulphide is lighter than cast iron and, in the cupola, has a tendency to rise and combine with the slag and thus separate out. The formation of this compound and its rising through the molten metal takes some time. This desulphurization is not complete, however long the iron is held, for some of the manganese tends to combine with carbon before all of the sulphur has been absorbed by it.

As has been said before, the effect of manganese on the qualities of castings is largely influenced by other elements present. Manganese has a tendency to decrease the porosity of the grain of castings by increasing the combined carbon, and by its desulphurizing and deoxidizing effects. The castings with closer grain stand pressure better.

The desirable amount of manganese in the mixture is determined not only by the proportions of the charge but by the method of operating the cupola. It is possible, with excellent cupola practice, to work with manganese below 0.5 per cent. In general, with good practice, manganese above 0.5 and under 0.8 per cent may be expected to decrease the sulphur, decrease the oxygen, soften and clean the castings, close up the grain, and decrease the foundryman's troubles from gases and shrinkage.

Topical Questions

1. (a) In what forms is manganese found in iron castings? (b) How are these materials distributed in the castings? (c) What are the effects, upon the qualities of castings, of the presence of these compounds?

2. What three chemical attractions of manganese are of great importance in the foundry? Explain in a sentence the effect of each.

3. See the table on page 86 of Spring showing the percentages by weight and volume of various elements in cast iron. Note that the percentages by volume of silicon and of sulphur are four times the percentages by weight while the percentage by volume of manganese is exactly the same as that by weight. What facts regarding these three elements and cast iron account for this relation of weight and volume?

4. In the open-hearth process of producing steel, why does the addition of iron oxide to the bath "keep up the boil until the test bars show that the carbon as well as the silicon and manganese have been eliminated as

fully as is desired?" (Spring, p. 152.) In other words, what causes the boiling?

5. With manganese above 0.8 per cent what difference can be expected between the qualities of thin and heavy section castings? Why?

6. What two good results from manganese in the mixture may not be obtained by adding manganese to the ladle? Explain.

7. Why is it claimed that manganese makes hard iron soft and soft iron hard?

8. Calculate the percentage of manganese in castings from the following mixture allowing for a 20 per cent melting loss of manganese. Show all calculations.

	Pounds	Manganese, percentage	Manganese, pounds
Pig, pile 1.....	600	0.75	
Pig, pile 2.....	300	1.50	
Pig, pile 3.....	200	0.50	
Heavy scrap.....	400	0.40	
Steel scrap.....	300	0.35	
Domestic scrap.....	200	0.55	
	2,000		

Text References

1. MOLDENKE, RICHARD, "Principles of Iron Founding," pp. 44-48, 123-124, 157, 216, 225-226, 237-239, 324-325, 410-412, 442-443.

2. SPRING, LAVERNE W., "Non-technical Chats on Iron and Steel," 2d. Ed., 1927, pp. 86 (table); 133-135, 144, 151-152, 233-236.

CHAPTER XLI

PHOSPHORUS AND ITS EFFECT ON IRON

Phosphorus like silicon and manganese, never occurs in nature in the free state. It combines so easily with oxygen that in one form it must be kept under water. This is white phosphorus which is poisonous and inflammable at 110° F. (Bradbury, pp. 516-522.)

Phosphorus is found in nature usually as metallic phosphate. A phosphate is a compound of a metal (or metal-like group of elements) with phosphoric acid. PO_4 is the combination of elements characteristic of phosphoric acid and phosphates, just as SO_4 is characteristic of sulphuric acid and sulphates.

The most abundant of the compounds of phosphorus is phosphate of lime ($\text{Ca}_3(\text{PO}_4)_2$). It is in this natural form that phosphorus finds its way into the blast furnace with the iron ores and thus into iron products. Life, both animal and vegetable, is to a great extent dependent on phosphates. Calcium phosphate composes a large portion of bones, and the by-products of packing houses are an important source of phosphorus in some forms.

The phosphorus found in pig iron comes mostly from the ore, but some is taken from the fuel and flux used in the smelting in the blast furnace. After the phosphorus has once combined with the iron it cannot be removed in the cupola. There is, therefore, practically no melting loss of phosphorus in the cupola. In other words, the percentage in the castings will be the same as the percentage in the mixture going into the cupola, except for a slight increase due to melting loss of other elements.

Since phosphorus has a very definite effect upon the qualities of castings and its quantity in castings cannot be modified by the proportions of other elements in the charge, it is

natural that many practical foundrymen accustomed to working with low phosphorus find it difficult to use pig iron or scrap with a higher percentage. Many important ore regions yield only high phosphorus iron, and the tendency today is to learn to use a wider variety of raw materials.

An important characteristic of phosphorus is the effect it has on the fluidity of molten cast iron. Fluidity is the property of flowing easily and thus filling all parts of the mold. In the making of such castings as stove parts, very light and thin sections, and ornamental work, fluidity is required in the molten metal. Fluidity in molten metal can be obtained either by altering the composition of the charge or melting at a higher temperature or by both means.

If fluidity were to be obtained largely by melting very hot, there might be difficulty from the sand. With the sand used for this class of work, a very rough casting would result. This roughness is due to the superheated iron having burned the sand at the high temperature. High silicon iron, which is expensive, has been much used in the past in order to get the fluidity needed for certain kinds of castings.

Many foundries making stove plate and light work, in recent years have found that by using a low silicon, high-phosphorus iron very good results can be obtained. This change has an advantage in a saving in the price of this kind of pig iron over that paid for a high silicon, low-phosphorus iron.

Phosphorus in large amount lowers the melting point of cast iron, but this effect must be distinguished from its power to increase fluidity. The fluidity of iron is increased by even a small increase in phosphorus.

Phosphorus tends to weaken cast iron and in amounts over 0.90 per cent makes the iron very brittle. One reason for this is the prolonging of the cooling of melted iron. This, as has been frequently mentioned, allows more time for the graphitic carbon to separate out, thus opening the grain and decreasing the strength.

Where strength is desired, the phosphorus content is sometimes kept as low as 0.15 per cent though 0.50 to 0.70 per cent is an ordinary amount.

Where fluidity in the molten iron is a more important factor than strength in the castings, the phosphorus may go as high as 1.0 per cent, but seldom above this as the iron would be very brittle. Stove plate usually runs about 0.70 per cent in phosphorus.

Oftentimes, foundrymen will find little globules of iron in cavities which are pockets formed in castings by occluded gases. Some foundrymen believe these globules to be shot caused by metal splashing in the mold, but if they examine these globules they will find that each is attached at one spot. This indicates that they have been segregated from the metal after the gas pocket has been formed, and have simply followed the path of least resistance in flowing or oozing out into these pockets. These globular masses have been found to be much higher in phosphorus than the remainder of the iron.

Phosphorus is unlike a number of other elements in that its percentage in the casting is influenced by the proportion in the pig iron and scrap and not by the chemical attractions of other materials in the cupola or ladle. The reason for this is that the chemical compound of phosphorus and iron is not easily broken down. The foundryman must decide, from the standpoint of the requirements of his pouring practice and the qualities of his castings, whether he can use high, low, or medium phosphorus iron. Since high phosphorus iron is fairly abundant and somewhat cheaper than low phosphorus iron, the advantage and difficulties in its use should be clearly understood.

Topical Questions

1. What weight of phosphorus in a ton of castings would be considered high? Low? What may the castings be in each case?
2. In outline form, indicate the effect of phosphorus upon six qualities of iron castings.
3. Which does phosphorus tend to do, soften iron or harden it?
4. Compare phosphorus with carbon, manganese, oxygen, and sulphur as to the strength of its chemical affinity for iron relative to the affinity for other elements. What is the practical effect of this fact in the calculating of charges?

5. If you were operating a foundry making light castings and the percentage of broken castings in the cleaning room was high, although you were sure that it was not negligence on the part of the mill room foreman, what would you consider the first thing to be looked into? Explain.

6. If you were casting gas engine pistons, would you use a high or a low phosphorus? Why?

7. What has been the experience in foundries with which you have had contact regarding the obtaining of desirable results in casting very light gray-iron castings with a high silicon, low phosphorus iron? Explain.

8. Why does phosphorus tend to open the grain of castings?

9. Compare phosphorus and carbon as to the method of reducing the amount in castings.

10. What is the variation in amount of phosphorus in pig irons? The standard? The allowable variations?

11. From the standpoint of phosphorus, why does adding steel to the mixture strengthen iron castings?

12. What is a possible danger in using stove plate and ornamental castings as scrap in a charge to be used for machinery castings?

13. How does the amount of heat produced by the complete oxidation of phosphorus compare with the heat produced by the oxidation of the same weight of manganese? Is heat produced in the cupola in this proportion from these two elements? Explain. How does this difference in oxidation affect the calculation of mixtures? (Moldenke, pp. 325 and 411.)

14. Does phosphorus act as an acid or a basic substance? What material of the other type is used to neutralize and carry into the slag the phosphorus in steel furnaces? (Spring, p. 230.)

15. In making castings having both light and heavy sections where some strength is required, approximately what percentage of phosphorus is it advisable to use? Why?

16. If you would use a low phosphorus iron in question 15, how would you run the light sections? Explain. If a high phosphorus, how would you meet the problem of differences in section?

Foundry Problems

A foundry is receiving complaints regarding piston rings. The difficulty is that the rings lack spring. The mixture used contains 0.80 per cent of phosphorus.

1. What are the two qualities particularly needed in piston rings? State briefly what would be the complaint if either of these qualities was lacking.

2. What change or changes would you advise in the mixture? Why?

3. What difficulty might arise in the pouring of the castings because of the change you have suggested in 2 above?

4. What other changes would you make in order to overcome the difficulty produced by the change suggested in 2 above? Why?

Text References

1. MOLDENKE, RICHARD, "Principles of Iron Founding," pp. 7, 49-51, 103-104, 125, 139, 209, 211, 216, 325, 411, 443.

2. SPRING, LAVERNE W., "Non-technical Chats on Iron and Steel," 2d. Ed., 1927, pp. 97, 144, 147-148, 152, 230.

CHAPTER XLII

SULPHUR AND ITS EFFECT ON IRON

Sulphur is found in the native state, especially in volcanic regions. It is a yellow-crystalline solid with a melting point of 238° F. It is, also, found combined with metals. Iron sulphide (iron pyrites) is very abundant and is the chief source of sulphuric acid.

Some of the ores from which pig iron is obtained contain so much sulphur (in the form of iron sulphides) that the ores are roasted in order to lessen this amount. Many iron ores contain at least traces of iron sulphides which find their way into the pig. Sulphides of copper and zinc are the principal ores of these metals.

Sulphur, as a general rule, is harmful to cast iron and for this reason manufacturers of pig iron are penalized for a high sulphur iron. Most foundrymen do not want pig iron with a sulphur content much over 0.05 and will not pay the regular price for an iron that is higher than that in sulphur. That this element is not without value in iron, in very small amounts, will be mentioned later.

Sulphur in pig iron comes largely from the fuel used in the furnace. When pig iron is remelted in the cupola about 20 to 40 per cent of the sulphur in the coke is absorbed by the iron. These figures are an average and depend largely on the operation of the cupola, quality and quantity of flux used, the temperature of the iron, and the rate of melting.

Sulphur combines with iron at low temperatures, so in a cupola melting with a low temperature more sulphur will be absorbed by the iron. The hotter the cupola, the more sulphur will be carried away by the slag. The chemical affinity between manganese and sulphur accounts for this.

Sulphur and silicon have practically an exactly opposite effect on the formation of graphitic carbon. Sulphur tends

to cause iron to retain the carbon in the combined form which, of course, is the reason for the statement that it makes iron hard. For every increase in the amount of sulphur, there is a corresponding increase in the combined carbon. Every 0.01 per cent of sulphur neutralizes as much as ten to fifteen times this amount of silicon in its effect on the carbon.

Sulphur causes the iron to set quickly and this results in the enclosing of gases, dirt, kish, and dross. Blow holes on the surface and dirty castings result. In addition to causing iron to lose its life in the ladle, with all the consequent ills from this source, sulphur increases shrinkage and chill, makes iron hard and brittle, and causes shrinkage cracks.

It would be a mistake to assume that iron with absolutely no sulphur is to be desired. The electric furnace made it nearly possible to entirely eliminate sulphur from iron, but experience with such iron led to a realization that sulphur in very small amounts seems to be essential in iron castings. This is particularly true when the castings have points of friction, as in bearings.

The dead line for sulphur in iron is usually considered to be 0.1 per cent. Amounts as low as 0.08 and even 0.04 per cent are often required. With even this amount, a good polish and resistance to friction are obtained. A firm that reduced the sulphur to a mere trace discovered another dead line, for their bearings were unable to stand service. Moldenke's statement, on page 447 of "*Principles of Iron Founding*," is in line with the experience of others who have found that "no sulphur" is not the ideal in certain kinds of iron castings.

Any iron remelted in the cupola will increase in sulphur content. For that reason, it is necessary for the foundryman to watch his percentage of scrap in the mixture, especially foreign scrap as this is sometimes very high in sulphur. The usual pick-up in sulphur is about 0.03, depending, of course, on conditions given in a preceding paragraph.

The sulphur in cast iron can be largely decreased by the use of manganese as this element combines with the sulphur to form manganese sulphide, which separates out and passes off in the slag. Manganese sulphide is lighter than the iron

and, therefore, floats on the bath of molten iron. This subject is discussed more thoroughly in the chapter on manganese.

The sulphur in the coke used in the cupola should be very carefully watched, as a high sulphur coke will tend to increase the sulphur content of the castings considerably. Good foundry coke should not contain much over 1 per cent in sulphur.

Desulphurization of Cast Iron.—Dr. Moldenke writes as follows of desulphurization processes:

It is the fate of all castings to eventually go into the scrap pile and in remelting to have the new material contain a slightly higher sulphur content; hence, the ever-increasing need of some method to overcome this objectionable condition. The simplest manner, that of diluting the sulphur content of the mixture with a high pig iron percentage, means more expensive mixtures. The best method, that of duplexing in the basic lined electric furnace, is too costly and not adapted for large tonnages. By simply allowing the molten metal to stand long enough to permit the manganese sulphide to rise and be skimmed off with the slag will cut the sulphur considerably, but this is risky and undependable; therefore, the desulphurization by chemical methods offers the best solution of the problem.

It has long been known that soda ash put on top of a ladle of molten iron and allowed to remain there as long as the iron can be safely held, will absorb much of the sulphur of the iron. Since, however, this action was very uncertain, soda ash has never been used commercially in this way. Recently, it was found that two factors were essential to assure success: First, all slag had to be skimmed off, otherwise the soda ash (crude sodium carbonate) would combine with it and not with the sulphur of the iron; second, when the reaction has taken place, the thinly liquid soda slag should be removed. This can be done by throwing on a quantity of air-slacked lime which absorbs and solidifies the liquid soda slag. The metal may then be poured off.

In the ultimate construction, either a forehearth may be used with the cupola with a slagging-spout between so that only clean iron may be treated or a mixing ladle with a teapot spout can be used. Soda ash, or any of the compounds containing it, can be thrown on the surface of the molten iron and the treated metal obtained from the forehearth or teapot spout. The quantity used is one-half of one per cent of the weight of the iron. The best results are obtained with soda ash previously melted in an iron crucible and poured into small cakes.

Dr. Richard Walter of Nuremburg, Germany, should be credited with the discovery of the practical application of soda ash as a desulphurizer. The desire of foundrymen to get rid of sulphur in mixtures has led to the manufacture of a number of commercial products to be used for this purpose.

Topical Questions

1. What is the relationship between long heats and sulphur increase in remelting? Explain.
2. If you were making stove plate or light gray-iron castings what amount of sulphur would you aim to get? Why?
3. How would you accomplish the desired result? Explain in detail.
4. In sampling pig iron how can a misleading result, as to sulphur content, be obtained? Explain.
5. What is the argument for the requirement that every piece of machinery scrap shows evidence of being tooled?
6. Both iron sulphide and manganese sulphide separate out in hard granules in iron castings. One of these substances is more commonly found in the interior of castings and the other, nearer the outside. Which compound tends to form in each location and why?
7. State the usual limitations, as to sulphur, in foundry materials and products.

Foundry Problems

A plant suddenly began to lose thousands of dollars worth of castings. A careful check revealed no change in materials or details of operation except that a similarity in numbers of freight cars had led to some coke being used in the cupola which had been purchased for use in the coke ovens.

1. Explain briefly in detail how difficulty might have resulted from the use of the coke intended for the coke ovens.
2. How could this be tested? Why was it important to know whether the coke might cause the trouble?
3. What do you think may have been the defects in the castings which had to be discarded? Do not repeat any part of a previous answer if you have mentioned these defects in answering a former question.

References

1. MOLDENKE, RICHARD, "Principles of Iron Founding," pp. 47-49, 146, 209-210, 216, 225-226, 251, 441-442.
2. SPRING, LAVERNE W., "Non-technical Chats on Iron and Steel," 2d. Ed., 1927, pp. 40, 168.
3. BRADBURY, ROBERT H., "A First Book in Chemistry." p. 186.

PART VIII
IRON

CHAPTER XLIII

OCCURRENCE

Certain characteristics of castings may be traced back to the pig iron which is one of the foundry's raw materials. Cost is always influenced by raw materials. It is of value, therefore, for the foundryman to know something about the sources of pig iron, the forms in which iron is found originally, the regions and countries from which it is obtained, the classes of ores, and the methods of mining.

Iron is found in a native state only rarely and this is in meteorites. It occurs chiefly in the form of ore. Ore is metal as it is extracted from the earth in its natural state or combined with other substances. Iron ores are native mixtures of compounds of iron with rock, earth, clay, and other impurities known as *gangue*.

Iron is found in nearly every country of the world. Next to aluminum, iron is estimated to be the most abundant metallic element in the earth's crust. Only a few countries, however, produce iron ores that are important commercially. Either the abundance is not sufficient to warrant mining or the iron content is too low to justify extraction.

The most important and largest producing iron ore beds are found in the United States; although Great Britain, Russia, China, Germany, and Sweden have large deposits.

The northern peninsula of Michigan along Lake Superior and the adjacent part of Minnesota produce a large part of the iron used in the United States. The Birmingham, Ala., district is another important region producing the third largest tonnage of any district. Next in order of importance in America are New York, Pennsylvania, Tennessee, and Virginia.

Iron is made chiefly from ores which are oxides of iron mixed with other elements and impurities. It will be remem-

bered that an oxide of an element is a compound of oxygen with the element. If an ore contains less than 40 per cent metallic iron, it is not profitable to use as the cost of smelting would be too great in comparison to the yield. As a metal becomes scarce, or as methods of smelting become cheaper, it sometimes becomes profitable to smelt ores that were formerly considered not rich enough in metal to be worth smelting.

The most important of the world's iron ores is *hematite*. It is found in both the red and the brown state. Brown hematite is another name for *limonite*. The red hematite is much the color of blood, the name having been taken from a Latin word meaning "bloodlike." The color of blood is due to the iron in it. The red hematite is much richer than the brown, containing about 60 to 65 per cent metallic iron. This is found chiefly in the rich beds of the Lake Superior region, although some is found in the southern region.

Magnetite is another form of iron ore. Magnetite ores are so named because of their magnetic qualities. This kind of ore is often concentrated or separated from the gangue by means of magnets. The gangue is the earthy or stony material associated with the ore. When pure, magnetite ore contains about 72.4 per cent metallic iron, but on the average it contains less iron than hematite.

Ores of the magnetite group vary in color from gray to black. The purest of these is found in the beds of Sweden. Most of the magnetite ores found in the United States are of a low-metallic content and, therefore, not desirable.

Another variety of iron ore is *siderite* sometimes called "carbonate." It contains a large percentage of clay and a small percentage of iron. It is of little importance in the United States because it is poor in iron and cannot compete with the rich hematite ores. It is always calcined before it is smelted, to expel the carbonic acid which is detrimental in the blast furnace.

There are two important methods of mining iron ore. One is surface mining; the other shaft mining in which a shaft is sunk into the deposit and the ore blasted down. With the exception of that in the Mesaba range of Minnesota, all the iron ore found in the United States is some distance

underground. This necessitates shaft mining. These shaft mines yield hard or lump ore.

Until the Mesaba district of Minnesota was discovered, blast furnaces had always used lump ore. This new district extending for approximately 100 miles brought to attention great quantities of ore which was not in the lump form nor was it buried deep underground. The ore found here is soft, rich, and very accessible. All that is necessary in mining is to strip the ground above the ore and begin to load the cars with steam shovels. Some difficulty was encountered, at first, in smelting this soft ore, but the difficulty has been overcome so that the Mesaba district is now one of the richest and most profitable districts in the world for the production of iron ore.

Topical Questions

1. Why did primitive people use gold and silver long before they used iron?
2. How should iron ore, which has a dark-gray appearance and is fairly rich in iron, be classified? Why?
3. If an iron ore contains approximately sufficient iron to be profitably smelted, about what percentage of impurities would probably be removed in its extraction?
4. Do you believe there may be a by-product in iron ore refinement? Explain.
5. What would be some of the possible effects upon world markets if the iron ores of Northern Michigan were found in equal abundance in certain other countries?
6. Explain and give an illustration of Slosson's statement that "The prosperity of modern states is dependent on the amount of iron rust which they possess and utilize."

Text References

1. MOLDENKE, RICHARD, "Principles of Iron Founding," p. 38.
2. SPRING, LAVERNE W., "Non-technical Chats on Iron and Steel," 2d. Ed., 1927, pp. 1-28, 33-36.
3. "The Story of Steel," United States Steel Corporation, *Bull.* 6, 5th Ed., 1927, pp. 5-16.

Reading References

1. "The A B C of Iron and Steel," 5th Ed., A. O. Backert, Editor, 1925, pp. 1-18.
2. SLOSSON, EDWIN E., "Creative Chemistry," "Metals, Old and New," Chap. XIV.

CHAPTER XLIV

TRANSPORTATION OF ORES TO FURNACES

One is inclined to ask why pig iron is manufactured 800 miles away from the mines, and one may even question whether this can be done economically.

As stated in the previous chapter, three-fourths of the ore used in the United States is mined in the northern peninsula of Michigan and the adjacent part of Minnesota; while, as is well known, the iron districts such as Chicago, Milwaukee, Gary, Cleveland, Pittsburgh, Buffalo, and Detroit where the iron is smelted, are many miles away. The process of smelting requires large quantities of fuel, coke being most commonly used. The iron districts are located closer to the supply of coke than to the ore.

It is natural to ask why the ore is brought to the coke rather than the coke brought to the iron. The coke necessary in smelting weighs approximately one-half as much as the ore with which it is used. Coke, however, is very bulky in proportion to its weight. In shipping coke, there is a great deal of waste because some of it breaks into very small lumps and is useless in blast furnaces. Iron, as might be expected, is not easily damaged in shipment.

Modern machinery and inventions have made it possible to mine, charge, and discharge ore in large units without its being touched by a shovel in the hands of a workman.

At the mines, large steam shovels pick up the ore and dump it into railroad cars, in which it is then carried to the shipping ports. The ore cars are run upon huge trestles above the ore bins high over the docks and their contents dumped into the bins.

The ore carrying boats are built of steel and have hatches on exactly 12-ft. centers. When a boat is docked, large steel chutes from the bins, which are also on 12-ft. centers, are

lowered into the boat. All the chutes to be used with one boat are opened simultaneously so that there is no danger of breaking the frail steel shell of which the boat is made or of upsetting its balance. Each boat carries approximately 10,000 tons of ore, and in less than an hour the boat is loaded and ready for its trip to iron districts.

When an ore boat arrives at its destination, it pulls up to the docks where huge clamshell buckets, on a bridge crane, descend into each hatch and grab 10 to 15 tons of ore at a bite and deposit it in huge piles. Other clamshell buckets take it from these piles and deposit it in bins. In 4 or 5 hours, the boat is unloaded, the ore not touched by the shovel of a workman throughout its entire route from the mine.

Topical Questions

1. What are the relative advantages of waterway and railroad transportation in the shipping of iron ore?

2. Mention two of the largest pig iron producing districts in the United States and show how their location is affected by the transportation of their raw materials.

3. Make a list of as many as possible of the kinds of labor-saving equipment which have made it possible to mine iron ore, transport, and unload it at the blast furnaces without touch of the human hand.

4. Suppose iron ore were found in a certain European country equal in abundance and quality to that in northern Michigan, what factors would determine whether that country could manufacture pig iron so economically as to compete with the American market in export?

Text References

1. SPRING, LAVERNE W., "Non-technical Chats on Iron and Steel," 2d Ed., 1927, pp. 28-33.

2. The Story of Steel, United States Steel Corporation, *Bull.* 6, 5th Ed., 1927, pp. 27-29.

Reading Reference

"The A B C of Iron and Steel," 5th Ed., A. O. Backert, Editor, 1925, pp. 33-60.

CHAPTER XLV

DESCRIPTION OF BLAST FURNACE

As pig iron is used in all ferrous foundries, something must be learned of its manufacture. It is the semi-raw material from which practically all iron and steel products are made.

Iron ore is charged into a blast furnace; and, by methods which will be described later, pig iron is produced.

The blast furnace is a tall, cylindrical stack which is lined with an acid refractory fire brick. In Fig. 53 are shown the various parts in the section of a blast furnace. The straight portion occupying the lower 8 ft. of the furnace is called the hearth or crucible. Just above this is a widening portion called the bosh. This extends to the widest part of the furnace. From there up to the throat is the stack.

The hearth or crucible, as shown in the figure, is at the base of the furnace. The size of course varies with the furnace, but in order to get an evenly distributed blast it should not be more than 15 ft. in diameter. The hearth is that part of the furnace to which the molten metal and slag run, and from which they are tapped out. To protect the hearth from the heat, water is allowed to trickle over the outside surface.

The bosh, which is directly above the hearth, is the hottest part of the furnace. In order to protect the furnace from the heat at this point, a number of hollow, wedge-shaped castings are placed among the bricks in the lining and cold water allowed to circulate through them.

The tuyeres pass air directly into the furnace below the combustion zone. The bustle pipes, which encircle the furnace, distribute heated air to the tuyeres. In order for these pipes to withstand the heat of the air passing through them, it is necessary to line them with fire brick. The free air in the bustle pipes has been heated by the burning of the

hot gases drawn from the upper part of the furnace, as will be described later.

The cinder notch, or "monkey" as it is sometimes called, is located about 30 to 40 in. below the level of the tuyeres and is used as a slag hole for tapping out the slag. A water-cooled casting protects it from the heat. The cinder or slag is never allowed to go above the level of the tuyeres.

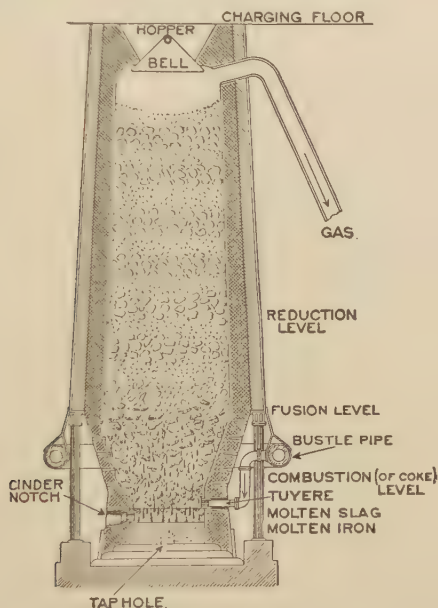


FIG. 53.—Diagrammatic sketch of blast furnace. (Reproduced from "Non-technical Chats on Iron and Steel," by LaVerne W. Spring, 2nd Ed., p. 57, 1927, by permission of the publishers, Frederick A. Stokes Company.)

In the front of the furnace and at the bottom level of the hearth, is the iron tap hole from which all the iron is tapped out. When the molten metal has accumulated sufficiently in the hearth, it is tapped out through the tap hole. This opening is closed with balls of clay.

At the top of the furnace are a bell and hopper. All material is loaded into skips running on a steep incline and dumped into the bell and hopper. The bell of the hopper is lowered and allows the charge to drop into a second bell and

hopper. The top bell is closed to prevent the escape of gases when the charge is dropped from the second hopper into the furnace. The material is spread evenly in the furnace on the top of the other material which is always kept up to within a few feet of the bell.

In the process of smelting iron ore in a blast furnace, one of the important items is the air used. This air is driven into the furnace by large blowers with a capacity of about 50,000 to 65,000 cu. ft. of free air per minute with a pressure of 15 to 30 lb. per square inch. It is because of this volume of air used in smelting that the term "blast furnace" originated. To melt 1 ton of iron, 4.5 tons of air are required. The weight of 50,000 cu. ft. of air varies from approximately 3 to 6 tons with gage pressures of 10 to 30 lb. at ordinary temperature, but this weight is fully twice that of an equal volume of air at the temperature in the bustle pipes.

The air before going to the furnace is heated to a temperature of 800 to 1200° F. This is done by means of hot-blast stoves which are cylindrical tanks made of steel, brick lined, about 100 ft. high and 20 ft. in diameter. Each furnace has 4 or 5 hot-blast stoves. Each stove has two or more fire brick chambers or flues and an open chamber. The principle of it is this—the waste gases from the top of the blast furnace are received at the bottom of the open chamber and mixed with air. They burn as they rise to the top, where they are deflected and are passed down through the fire brick chambers. Most of the heat from the burning gas is taken up by the fire brick. When they are heated, the stove is ready for the air.

The air to be heated enters the furnace at the bottom of the flues, passes upward through them, down through the open chamber, and out to the bustle pipe of the blast furnace. In its course of travel, the air acquires a temperature of 800 to 1200° F. and is then ready for use as a hot blast.

Topical Questions

1. Where is pig iron a finished product and where is it a raw material? Explain.
2. Why is an acid fire brick used in the lining of a blast furnace?

3. What are three of the ways in which the specific gravity of materials is made use of in the design of a blast furnace? Mention in each case the material, its relative weight, and the use made of this fact.

4. Why must the blast be distributed equally?

5. If a blast furnace has an output of 600 tons per day, how many tons of air would be required to melt this amount?

6. One thousand cubic feet of air at ordinary room temperature and atmospheric pressure (0 gage pressure or 14.7 lb. per square inch) weighs 74.7 lb. Using any table of reference, find the weight of this volume of air at 30 lb. gage pressure, the temperature being the same, and also the weight at 0 and at 30 lb. gage pressure with a temperature of 600° F. Put these data in the table below.

	Weight of 1,000 Cu. Ft. of Air	
	0-lb. gage pressure	30-lb. gage pressure
Room temperature	74.7 lb.	
600° F.		

7. Give an example from your own observation of the conservation of heat similar to that in the heating of the blast in a smelter.

8. What are important similarities and differences between the blast furnace and the cupola?

Text References

1. SPRING, LAVERNE W., "Non-technical Chats on Iron and Steel," 2d Ed., 1927, "The Blast Furnace," Chap. IV.
2. MOLDENKE, RICHARD, "Principles of Iron Founding," pp. 12, 53.

CHAPTER XLVI

OPERATION OF BLAST FURNACE—SMELTING PRACTICE

In the preceding chapter the different parts of the blast furnace were explained and now its operation in the making of pig iron will be considered.

The materials used in the reduction of the ore to pig iron are fuel, (coke, coal, or charcoal) flux, (usually limestone) and ore. They are charged into the furnace (on the bed) in alternate layers. First the fuel, next the flux, and then the ore. The thickness and number of these layers are dependent upon a number of factors. When the fuel begins to burn, certain chemical reactions begin to take place in the furnace. Naturally, the hottest part of the furnace is at the smelting zone and the reactions due to the high temperature are different there than they are farther up the stack. In fact, all the way up the stack to the stock line, different temperatures are found, and at each temperature different chemical reactions take place. Whatever other reactions are taking place, oxygen is leaving its combination with the iron in the ore and is entering into combination with the carbon in the fuel. That is, as the fuel is oxidized the iron ore is reduced. This continues as the charges descend in the stack until, at the smelting zone, the iron practically is free from the oxygen and, due to the high temperature of 2800 to 3000° F., it is in the molten state ready to be tapped out. A part of the carbon of the fuel and oxygen in the ore have combined to form a gas which goes out at the top of the furnace, then through dust arresters, scrubbers, water separators, and other units, and thence to the hot blast stoves, boilers, or wherever else it may be used.

The flux or limestone in the charge has combined or mixed with the dirt and other impurities of the ore and separated

out as slag. This slag has a lower specific gravity than the iron and therefore floats on top of the iron. It is allowed to accumulate until it is nearly to the top of the tuyeres; then the cinder notch is opened by withdrawing the iron plug and breaking through the chilled cinder or slag with a sharp steel bar. The slag flows down a runner for 15 or 20 ft. into a ladle in which it is taken to the slag dump. A furnace is usually slagged out four or five times between every tap of iron. In recent years, the cinder or slag has come to be used to some extent in the manufacture of Portland cement.

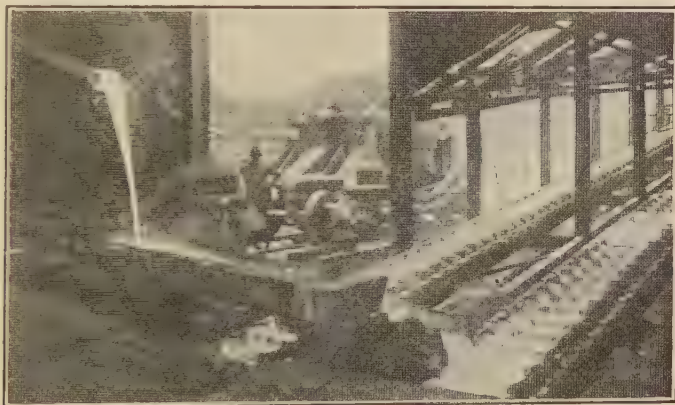


FIG. 54.—How pig iron is now cast into traveling molds. (Reproduced from "*Non-technical Chats on Iron and Steel*," by LaVerne W. Spring, 2d Ed., p. 65, 1927, by permission of the publishers, Frederick A. Stokes Company.)

After the slag has all been taken out of the furnace and the hearth is full of iron, the tap hole is drilled out by means of a power-driven drill. The iron is run into ladles along side the cast house and from them poured into a pig casting machine. This consists of hollow metallic molds which are carried on an endless chain. When the iron is poured into the molds it sets quickly. The machine carries the filled molds up an incline where the pigs fall from the molds into railroad cars which carry them to the foundry. A photograph of this operation is shown in Fig. 54.

Pig casting machines are comparatively new and in some places the iron is still cast in sand pig beds. In the latter case, the iron runs out of the tap hole into the main runner of

the pig bed. This extends down the center of the bed. At the end of the main runner, the iron divides and fills the laterals or sows on each side and finally the molds for the separate pigs. Silica sand is used in the making of the molds. A plan of a pig bed is shown in Fig. 55. After the iron has cooled, the pigs are broken away from the sows and the latter are broken up with a sledge. All of the iron is then thrown into cars ready for distribution to the foundries.

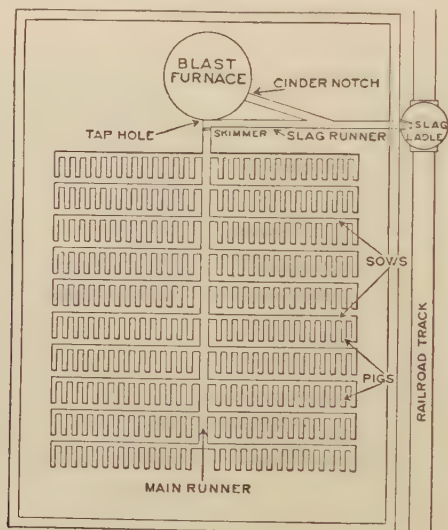


FIG. 55.—Old-fashioned pig bed. (Reproduced from "Non-technical Chats on Iron and Steel," by LaVerne W. Spring, 2d Ed., p. 58, 1927, by permission of the publishers, Frederick A. Stokes Company.)

Although in these chapters the only concern is with the manufacture of pig iron, it must not be thought that all of the iron ore smelted is used for making foundry pig iron. In most of the large steel works, the greater part of the molten iron is charged directly into either Bessemer or open-hearth furnaces and made into steel. In fact, quite often the metal is converted directly into steel plates, rails, etc., before being allowed to cool.

Topical Questions

1. Why is the treatment of iron ores in a blast furnace spoken of as a reduction process?

2. What are two important differences between the use of charcoal and of coke (or coal) in the blast furnace?
3. Why is charcoal iron produced more abundantly in northern Michigan than in any other part of the United States?
4. Why does limestone act as a flux?
5. Pure iron at ordinary furnace temperatures is a pasty mass and does not flow readily. How do you account for the free flow of iron from the blast furnace?

Text Reference

1. MOLDENKE, RICHARD, "Principles of Iron Founding," "The Blast Furnace," pp. 70-74.

Reading References

1. "The A B C of Iron and Steel," 5th Ed., A. O. Backert, Editor, 1925, pp. 77-92.
2. RHEAD, E. L., "Metallurgy," "Iron Smelting," Chap. VIII.

CHAPTER XLVII

CLASSIFICATION OF PIG IRON

The product of the blast furnace is pig iron. As has been stated in a previous chapter, a large part of the pig iron made in this country is used in the manufacture of steel. A portion of it is puddled and becomes wrought iron. Here, however, the primary interest is in the pig iron that is used in the manufacture of iron castings.

As a general rule in the foundry trade, all pig iron is purchased by specifications. It will be necessary, therefore, to go somewhat into detail as to how pig iron is classified.

A few years ago a foundryman had to choose between two kinds, machine-cast pig and sand-cast pig. Sand casting was carried on for many years before machine casting was devised. When machine-cast pig iron was introduced, many foundrymen thought that it would not be as desirable as sand cast due to the chilling action of the metal molds on the iron. It was thought this would have a bad effect on the castings.

It will be remembered from the study of the effect of carbon on iron, that a large proportion of carbon is held in combined form when iron sets quickly and that the result of this is a greater chill. Machine-cast pig, of course, cools more rapidly than sand cast, and so this chilling was expected.

Many tests were made by foundrymen and it was found that machine-cast pig had several advantages. It is true that, due to the greater percentage of combined carbon, machine cast is harder than sand-cast pig iron, yet the castings have the same analysis as if sand-cast pig were used. Besides being free from sand, machine-cast pig is more uniform, presents a closer grain, is cleaner, and easier to melt. As a result, machine-cast pig has rapidly replaced sand cast so that now it is almost universally used.

When the foundryman is ready to purchase pig iron, he usually knows the chemical composition and physical stand-

ards he wants to maintain in his castings. He knows, also, whether he needs to use any high-grade metal such as charcoal iron, or brands particularly known for their high quality. If a very high-grade pig is required, he first finds the plants producing the particular quality desired, and then chooses, from the furnace specifications submitted, brands having the silicon, phosphorus, manganese, total carbon, and sulphur limits within his requirements.

It would be impossible for the furnace to produce iron to exact specifications so it is a common rule that the following variations are allowed:

	Per Cent
Silicon.....	0.25 either way
Phosphorus.....	0.20 either way
Manganese.....	0.20 either way
Sulphur, maximum as specified	
Total carbon, minimum as specified	

Thus, if the foundryman specified a pig iron analysis of 2.25 per cent silicon, 0.60 per cent phosphorus, 0.75 per cent manganese, 0.4 per cent sulphur, and 3.50 per cent total carbon, the furnaceman could ship him iron of 2.00 to 2.50 per cent silicon, 0.40 to 0.80 per cent phosphorus, 0.55 to 0.95 per cent manganese, not more than 0.04 per cent sulphur and not less than 3.50 per cent total carbon. This iron would be within his specifications.

The term "point" is commonly used in reference to the less abundant constituents of iron. A point is a hundredth of a per cent of a constituent of iron based on the total weight of iron. An increase of 15 points of silicon means an increase in silicon equal to 0.15 per cent of the total weight of iron. If the original amount of silicon is 1.85 per cent the increase of 15 points will bring the silicon up to 2 per cent.

The United States Government through the Federal Specifications Board issues a statement grading pig iron into four general classes for use in government foundries, as follows:

TABLE IX.—GRADES OF PIG IRON

Grade	Silicon, per cent	Sulphur, per cent, maxi- mum	Manganese, per cent	Phosphorus, per cent	Total carbon, per cent, minimum
No. 1..	2.75 to 3.25	0.04	0.50 to 1.00	0.50 to 0.80	3.40
No. 2..	2.25 to 2.75	0.05	0.50 to 1.00	0.50 to 0.80	3.20
No. 3..	1.75 to 2.25	0.05	0.50 to 1.00	0.50 to 0.80	3.20
No. 4..	1.25 to 1.75	0.05	0.50 to 1.00	0.50 to 0.80	3.20

Most of the furnaces produce pig irons falling within these standards. Much of the pig iron purchased today is bought by specifying the brand, which is usually the name of the furnace, and the grade number. Thus, Federal No. 2 pig iron would mean that it must come from the Federal furnace and be within the specifications for No. 2 iron.

Many of the foundries today cannot buy their pig iron under the above specifications due to the peculiarity of their work, such as an extremely low phosphorus requirement. Indeed, practically all of the important foundries having metallurgical laboratories to watch their practice, decline to use specifications with such wide limits and make their own specifications for each element, being, however, governed by the table of variations (tolerances) as above given.

It is no more than fair that the foundryman check his shipments of pig iron to see that he gets what he orders. In order to assure that both furnaceman and foundryman get a square deal, it is necessary that methods of analysis and sampling be made under standards acceptable to both parties.

The following is a copy of the standard methods for sampling and analysis of pig iron as adopted by the American Society for Testing Materials. It is a standard adopted by all foundries and furnacemen.

Pig iron. One pig shall be selected at random from each 4 tons of iron and 10 such pigs (representing 40 tons of iron) shall constitute a unit for sampling. The surface of each pig shall be cleansed with a stiff wire brush or in any manner that will remove all loose sand without introducing deleterious matter.

The skin, down to clean metal, shall then be removed with an emery wheel at the center of the upper face of each pig, and the surface carefully brushed off.

Drilling shall be taken with a $\frac{1}{4}$ in. twist drill, from top to bottom of each pig, starting from the center of the cleared space and stopping when the point of the drill appears below. One hole, only, shall be bored in each pig.

Suitable precautions shall be taken to prevent the escape of fine particles during the drilling. To this end, a disk of clean sheet metal shall be clamped upon the pig after the skin has been removed. This disk shall have a hole in its center just large enough to receive the drill. Most of the drillings will then accumulate on top of the disk and can be brushed off after the drill is withdrawn. The pig shall then be turned bottom side up over any suitable receptacle for collecting what may have remained in the drill hole.

Topical Questions

1. How may a knowledge of the composition of off iron help a foundryman to use such material to advantage in the mixture?
2. How do you account for the fact that upon remelting, machine-cast pig and sand-cast pig give practically the same analysis in the castings?
3. If you were making machinery castings of ordinary strength, what grade or grades of pig would you use? State composition of these as to elements.
4. For what kind of castings would No. 1 pig be essential? Why?
5. Why is No. 1 higher in price than No. 2? State definite basis for a difference in price.

Text References

1. MOLDENKE, RICHARD, "Principles of Iron Founding," pp. 4, 42-43, 146, 150, 202-219, 236.
2. SPRING, LAVERNE W., "Non-technical Chats on Iron and Steel," 2d Ed., 1927, pp. 61-66, 161-168.
3. Specifications No. 126a, "Foundry Pig Iron," March 1928, Federal Specifications Board, U. S. Dept. of Comm.

CHAPTER XLVIII

SCRAP

The use of scrap is an economy for the individual foundryman and a matter of conservation for the metal resources of the world. Scrap, as used in foundry charges, includes all metal which has been through the cupola once and is to be remelted.

The history of the scrap market in the last decade is an interesting example of the manner in which international relations, economics, and technology may be interrelated in the daily problems of a foundryman. These are involved in the age old change of the sword into the plough share.

After the World War closed, there was an immense amount of metal in useless form. The iron scrap market became depressed and scrap was very cheap.

The furnacemen who had been smelting ores with 50 per cent of iron could buy 100 per cent iron at an inviting price. This meant less slag and therefore more efficient operation of the blast furnace. The use of scrap in blast furnaces increased up to as much as 50 per cent of the charge.

Without entering into the debate as to the effect upon pig iron of the use of scrap in the blast furnace, it may be noted that, from many parts of the country, complaints were heard about excessive shrinkage ascribed to pig iron produced in part from scrap. But most innovations have produced problems in adjustments, and many have received more criticism than was merited. If the results contribute to economical production, the difficulties will be overcome, and the criticism will either be justified or discredited.

Without any regard to the use of scrap in the production of his pig iron, the foundryman is concerned with his own use of scrap in the production of castings. Fifty-fifty of scrap and pig is common practice. In some classes of work or

under peculiar conditions of production, a foundryman may produce as much scrap as castings, thus providing fully for the scrap in his mixtures. It is possible, but usually impractical, to melt scrap alone. If a foundry does not produce all the scrap it can melt, *foreign scrap* is purchased to add to the domestic or home produced variety.

The immense amount of scrap on the market is quite accurately graded and the foundryman needs to know what he can expect of the different grades and varieties.

Domestic scrap consists of over iron, sprues, gates, defective castings, iron from the cupola drop and gangways, in fact, all iron which, for any reason, is to be remelted in the foundry in which it was first melted. It is the duty of every foundryman to keep this scrap as low as possible, inasmuch as the pound cost is the same as the molten iron in the ladle plus labor and melting loss when again melted.

Another reason for keeping scrap down, is the effect of remelting in reducing the amount of a desirable element, silicon, and increasing the amount of an undesirable one, sulphur. If the sulphur is high the manganese, also, may be reduced.

In any well run shop, sprues and gates are carefully watched, with the idea of keeping them as small in quantity as is possible without jeopardizing the castings. Most foundries have iron pig beds distributed near the molders where they pig what iron is left in the ladle after pouring the molds. Oftentimes the amount of pig bed can be materially reduced by careful attention to this source of possible waste. A simple but surprisingly rare use of this pig bed in the foundry is mentioned later in connection with the use of iron borings.

Every foundryman should know the analysis of his own return iron as it, of course, is the same composition as the castings. If this iron scrap is allowed to accumulate from day to day, it is apt to cause trouble when used later. The mixture from which it was made might have varied considerably from the standard mixture. It should be the aim, therefore, of every foundryman to use, as nearly as possible, his own return iron every day.

In cases where the domestic scrap has accumulated, due to bad iron, oxidation, or bad coke, this iron should be kept separate. Formerly, this was thrown away or sold at a very low price, but this practice was uneconomical enough to absorb the present margin of profit.

When iron is giving much trouble, the quickest way of letting the iron get straight is to start out anew with all pig iron and no remelt. This gives the foundryman a chance to figure his mixture exactly. Then when the charges are giving a satisfactory product, the troublesome scrap can be used regularly in such small quantities as not to upset the mixture. In this way an accumulation of very bad scrap can be gradually used.

Many foundries free the sprues and gates from the burned sand by running them through the tumbling barrels before sending them to the charging floor. Authorities seem to disagree on this point. Some claim that the sand on the sprues and gates causes an undue amount of slag in the cupola. Others do not believe that the sand is injurious enough to warrant the expense of cleaning the scrap in the tumbling barrels.

When running large heats in large sized cupolas, there is always a great amount of iron in the drop. This can be separated by hand, but it is a costly process and not altogether satisfactory, inasmuch as it is impossible to separate all the iron from the coke. Magnetic separators are used in the majority of foundries today for this purpose and are very satisfactory in reclaiming the iron in the drop.

Foreign scrap includes all the iron to be remelted which is obtained outside the foundry where it is to be used. It is classified first, according to the kind of metal, as gray-iron scrap, malleable scrap, and steel scrap.

Gray-iron scrap is again subdivided into several varieties—machinery, agricultural, stove plate, car wheel, grate bar, brake shoe, and borings.

The most important of these is machinery scrap which, as its name implies, is broken, or worn-out, or discarded pieces of machinery. It is usually divided into two classes—pieces weighing under 100 lb., and scrapped machines in

unbroken state. Machinery scrap is undoubtedly the best grade of scrap to use in the cupola, as it is usually a good grade of cast iron running between 2.00 and 2.25 per cent in silicon. Of course, when buying engine beds, fly wheels, etc., the silicon will drop lower than 2.00 per cent.

Agricultural scrap consists of pieces taken from agricultural implements. If any chilled plow points, steel, or malleable come in the car of this material, they should be removed as their silicon content is much lower than that of the other parts.

Stove plate scrap consists of old stoves, radiators, kettles, sad irons, and almost any iron the junkman happens to pick up. As a rule, this scrap is very undesirable, especially in the making of light castings. It usually runs very high in phosphorus, and is apt to have burned grate bars which are very harmful in the mixture.

Car-wheel scrap is made up of discarded railroad wheels. It has a low silicon and high sulphur content. Much of this kind of scrap goes back to the car-wheel foundry though it is very desirable in any foundry, as definiteness of composition is always an asset in any part of the charge.

Car wheels have a definite composition which is frequently tested in their places of production. They must have a certain composition in order to stand the tests imposed on them and give the service demanded. Every possible means are taken to produce railroad car wheels which will not break in service. On the contrary, scrap sash weighs are most varied as to constituents.

Brake-shoe scrap consists of worn-out brake shoes and may be divided into those with steel inserts and those without. This scrap is not desirable in most foundries and usually goes back to the brake-shoe foundry or to a sash foundry.

Grate-bar scrap is usually desirable after the burned grates have been sorted out. Most of the grate bars come from the railroads.

Borings include the turnings from machine shops, and although many foundries are using them daily, their use often does not give perfect satisfaction. They are so light that the blast may carry a considerable part out of the stack,

covering the adjacent roofs. Two effective methods are the Prince method of melting borings in tubes and that of briquetting the borings. The melting loss in the former case runs about 12 to 18 per cent (Moldenke, p. 230), and there are other disadvantages. In the latter case, the cost of equipment to briquette is higher than most foundries can afford.

An inexpensive method that has been used to melt tons of iron borings in the foundry, is to shovel the borings on top of the pig as soon as the iron has been poured. Where this is the practice, the machine shop delivers the borings to bins on the casting floor, thus reducing the cost of handling which is always a large item with borings. In general, however, the chances of the borings being oxidized by rust or by heat are so great that their use in the cupola mixture may be the cause of heavy shrinkages and pin and gas holes in the work. Hence, borings, turnings, shot, and very light and small screenings are best sold to the blast furnace.

In discussing steel scrap, only medium sectioned pieces that will easily go into the cupola and will melt readily should be considered. Light steel scrap and punchings should be avoided, as they may cause considerable damage in the cupola. This is due in part to the variety of composition and also to the possibility of the production of oxidized iron. Steel rails, scrap angles, beams, and tees are the best for cupola practice. Steel melts at a higher temperature than pig iron and, therefore, should be placed on top of the layer of coke in a charge. Then the pig iron is placed on the steel and last the gray-iron scrap.

Topical Questions

1. What are four factors that influence the amount of domestic scrap in a foundry? Give an example of the operation of each.
2. Locate the immediate responsibility for the reduction of the various kinds of domestic scrap.
3. Under what conditions may it be advisable not to charge any scrap temporarily? What can be done with the scrap that accumulates at this time?
4. From a comparison of the melting points of steel and iron, what limitation would seem to be advisable in the size of steel scrap in an iron foundry? Why?

5. Explain any other limitation as to the size of steel scrap that may be necessary in an iron foundry.

6. Why are burned grate bars objectionable in the mixture?

7. In what kind of scrap is the phosphorus highest? Why?

8. Why is less than 2.00 per cent of silicon to be expected in engine beds?

9. In putting borings from the machine shop into the pig bed, what might happen if they were put in first and the molten iron poured over them?

10. If a foundry has used only domestic scrap for some time, what change will have occurred in the percentage of silicon, sulphur, manganese, and phosphorus, if no attempt has been made to control their amount? What is the reason of each?

11. Why do the specifications for some kinds of scrap require that it show evidences of having been machined?

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1. MOLDENKE, RICHARD, "Principles of Iron Founding," pp. 219-234.

PART IX
THE CUPOLA

CHAPTER XLIX

DESCRIPTION OF THE CUPOLA

Different types of furnaces are required for melting various kinds of metal. Only those in most general use will be considered in these chapters.

Most iron foundries make use of either the cupola or the air furnace. The greater amount of gray iron is melted in the cupola and a small but increasing amount in the electric furnace. Almost all malleable iron is melted in the air furnace. Each of these types has certain advantages and disadvantages. The air furnace requires much higher skill in operation than the cupola and its product is somewhat higher in cost than cupola iron. The advantage of the air furnace is that there is better control of the composition of the iron, especially as to the percentage of carbon and sulphur, than is possible in a cupola.

In Fig. 56 is shown the vertical section of a cupola and in Fig. 57 is shown a horizontal section of the same cupola. The essential parts are indicated in these figures. As the sketches indicate, the cupola is a simple stack having a steel shell closed at the bottom and open at the top; a lining proper of fire brick; a rammed-in or daubed-on lining containing fire clay; a door for charging fuel and metal; openings for an air blast; spouts for drawing off metal and slag; and bottom doors. A brief description of the various parts is necessary to an understanding of the operation of the cupola.

The shell is of boiler plate from $\frac{3}{16}$ in. to $\frac{3}{8}$ in. thick according to the size of the cupola. The shell is lined with fire brick and cupola block. The size of a cupola is indicated by the diameter inside the lining, and the thickness of shell and lining is governed by this size. Thus a 24-in. cupola will require an 8-in. lining; the shell diameter will be 40 in. and the shell thickness $\frac{1}{4}$ in. In this particular size, the

8-in. lining may be in one course of 8-in. cupola blocks or in two courses, one of 2-in. brick next the shell and an inner course of 6-in. cupola block. The double lining is less likely to burn through to the shell and is less expensive to replace than the single-course lining.

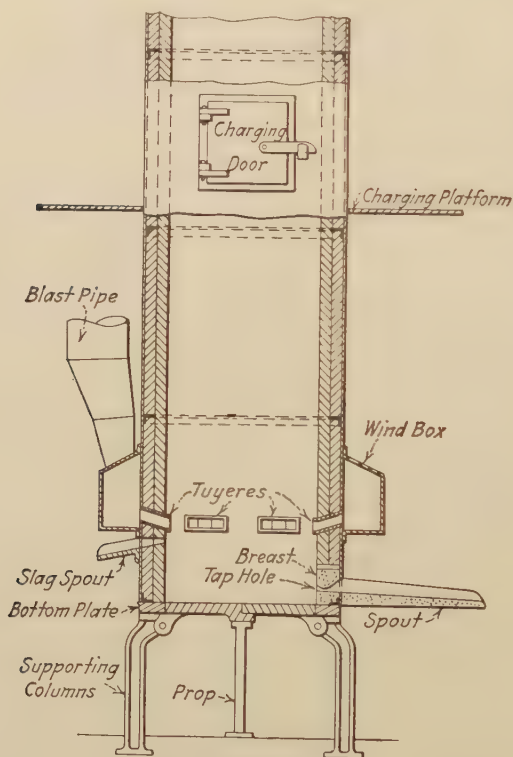


FIG. 56.—Vertical section of cupola.

The material used in the charge is introduced through the charging door which is located from 10 to 15 ft. above the bottom of the cupola. The particular height selected for the charging door depends upon many factors. Experience has shown that 15 ft. or more is a suitable height for most cupolas, while for continuous operation and in large units nearly twice this height may be used.

Due to the fact that the air necessary to consume the fuel and melt down the metal must pass up through many feet of broken up metal and coke, natural draft will not suffice. Air must be supplied under some pressure and introduced as near the bottom as the desired level of molten iron will permit. It is necessary that it enter at several openings to secure uniform distribution through the fuel. For this purpose an annular box, known as the *wind box* is built on the cupola shell just above the spouts. From this wind box the air passes into the cupola through cast iron ducts called *tuyeres*, which are built into the lining. These are shown in Fig. 57.

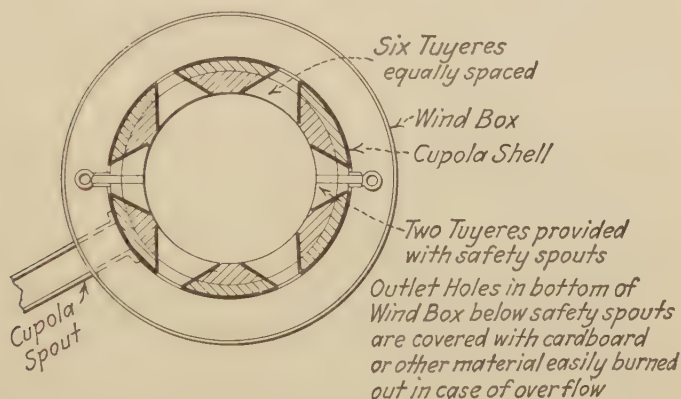


FIG. 57.—Cross-section of cupola.

The tuyere is usually flaring in shape, the large end being on the inside in order to make the blast as nearly uniform as possible, and because the coke of the fuel bed interferes to a great extent with air entering through the openings. The combined area of the tuyeres, measured at the small or outer end, is usually given as 15 to 20 per cent of the cross-sectional area of the cupola inside the lining. Dr. Moldenke suggests one-seventh or approximately 14 per cent for a 54-in. cupola, with double the area, 28 per cent, for the inner or lining end. A concern which has been in this field over 40 years builds cupolas in which the tuyere area ranges from $14\frac{1}{2}$ to 20 per cent.

Air is delivered to the cupola through the blast pipe by a blower. The continual improvement in the equipment for this delivery of air reflects the progress in foundry practice dependent upon more accurate measurement a fact to which frequent reference has been made.

Thirty years ago the ordinary belt-driven fan blower was commonly used. The supply of air was measured by pressure. These blowers are yet found in small foundries and in less progressive plants. In foundries where better control of melting has been established, the old type belt-driven fan has long since disappeared. The direct motor drive replaced the belt, and in turn the positive pressure blower and the centrifugal-type fan began to interest foundrymen. This interest has grown steadily as is evidenced by numerous installations.

The success of the positive blower was based upon its ability to deliver a definite volume of air to the cupola in a given period of time. With the old fan-type blower, a reduction in tuyere area resulted in a reduction of air supply with consequent cold iron, although the pressure might remain unchanged. The positive blower forces the same volume of air through the tuyeres regardless of considerable reduction in area. In the case of the centrifugal type of blower, which is a marked improvement over the old type fan blower, the volume is controlled by means of a blast gate in the line between the blower and the cupola.

This change in equipment insured the delivery of a desired volume of air to the cupola rather than the maintenance of a certain pressure. The change in the measure of the air was from pressure to volume.

While the positive blower assures a definite volume of air, this does not give the needed control of the amount of air or its active part, oxygen. It is a well-known fact that the weight of a given volume of air differs considerably under different conditions.

In the description of the blast furnace, mention was made of variations in weight of a given volume of air at different gage pressures. With the temperature constant, the volume of air which weighs 3 tons at 10 lb. gage pressure will weigh

approximately 6 tons at 30 lb. gage pressure. The atmospheric pressure does not vary as much as gage pressure, but it does change enough to influence greatly the weight of a given volume of air. Zero gage pressure equals atmospheric pressure, the exact amount of which is influenced constantly by altitude and irregularly by weather variations.

The weight of a given volume of air is influenced by pressure and temperature and to a slighter extent by the degree of humidity. The average atmospheric pressure at sea level is 14.7 lb. per square inch and at 1,500 ft. above sea level it is 13.9 lb. per square inch. A variation of 0.7 or 0.8 lb. per square inch in atmospheric pressure in a given locality is of frequent occurrence. The air delivered to the cupola may vary in temperature at different seasons of the year from below zero Fahrenheit to above 100° F.

The lower the atmospheric pressure and the higher the temperature, the less the weight of a given volume of air; conversely, the colder the weather and the higher the pressure, the greater is the weight of air.

The following table shows the variation in the weight of 10,000 cu. ft. of air, with temperatures from 0 to 100° F. and atmospheric pressures of 14.0 and 14.7 lb. per square inch. The lowest weight shown, 674 lb., is at 100° F. and 14.0 lb. atmospheric pressure; and the greatest weight, 864 lb., is at 0° F. and 14.7 lb. atmospheric pressure. This is a difference of nearly 30 per cent in a range of temperature and pressure less than that which may occur in the average foundry in the course of a year.

TABLE X.—THE WEIGHT IN POUNDS OF 10,000 CU. FT. OF AIR

Temperature, degrees Fahrenheit	Atmospheric pressure	
	At 14.0 lb. per square inch	At 14.7 lb. per square inch
0	820	864
32	768	807
70	711	749
100	674	709

A change from 768 to 864 lb. or 674 to 749 lb. as the weight of each 10,000 cu. ft. of air supplied the cupola, that is, a change of about 11 to 12 per cent, may occur overnight when the thermometer changes 30 deg. and the barometer 0.7 in.; and this is not the full extent of the variation due to weather. The humidity, involving tons of water vapor carried through

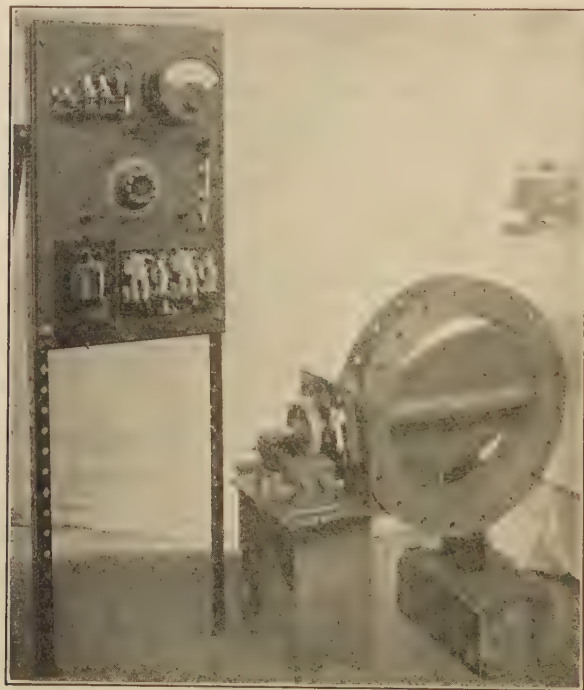


FIG. 58.—Automatic gate and control panel for G.-E. blower. (*Courtesy of General Electric Company, Schenectady, New York.*)

the cupola by the blast, is a further factor in the influence of the air supply upon cupola operation.

The influence of the weather upon the cupola is well known to practical foundrymen. This is easy to understand when one calculates how the supply of air, kept at a constant volume, is varying in weight of oxygen.

This variation of oxygen content challenges the interest of progressive students of foundry practice. The present situ-

ation with regard to control of oxygen entering the cupola is comparable to the situation encountered in the past by Dr. Moldenke, Thomas D. West, and other pioneers. They advocated the analysis of pig iron and scrap when the great crusade for accurate measurement of foundry materials was begun. Progressive foundrymen now take the analysis of pig iron, scrap, and castings as a matter of course, but they are only beginning to appreciate the importance of measuring and controlling the oxygen delivered to the cupola.

Since oxygen enters the cupola with the nitrogen of the air, and, like all other gases, is subject to equal expansion and contraction, it is apparent that if it is to be measured accu-

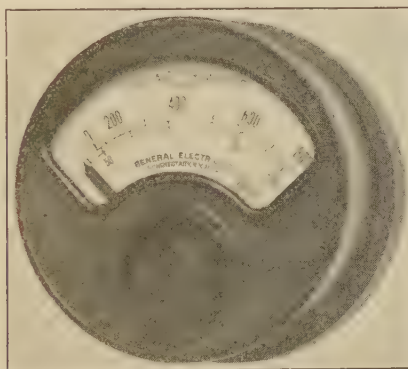


FIG. 59.—Meter for centrifugal air compressors showing pounds of air per minute. (Courtesy of General Electric Company, Schenectady, New York.)

rately, the air supply must be measured by weight. Some type of device for weighing the air passing from the blower to the cupola would offer the best opportunity for accurately gaging the weight of oxygen whatever may be the atmospheric changes in pressure, temperature, and humidity.

Whatever type of blower is used, the aim should be to furnish the weight of oxygen needed in melting. Metal, fuel, and air are, in reality, the three constituents of the charge. The pounds of all the important elements in these constituents, except oxygen, are known to the foundryman. It is only a question of time before this information regarding oxygen is considered essential in efficient cupola operation. How far

in the future this may be, it is difficult to forecast, but the trend is unmistakable.

The weight of oxygen supplied per unit volume of air depends upon the atmospheric conditions just discussed. The weight needed to melt a ton of iron is influenced by the conditions of operation and by the melting ratio—the weight of iron to weight of fuel. The melting ratio may be as high as 10:1 (10 tons of iron to 1 ton of coke) even 14:1 or as low as 4 or 5 to 1. The volume of air needed to melt 1 ton of iron is commonly estimated from 30,000 cu. ft. to 21,200 cu. ft. The range is even greater than this when consideration is given to the melting ratio and the weight of oxygen in air under different atmospheric conditions.

Whatever calculation based on theory is made as to the amount of air needed in the cupola, it must be checked in practice by the economical production of molten iron of the desired quality. Too little air, for the same height of bed, will result in the formation of carbon monoxide gas, cold iron, and other difficulties. Too much air, similarly, will produce oxidized iron, will increase the normal loss of metal in melting and lead to other difficulties.

While air weighing devices mark an advance in cupola control, students of industrial practice should understand that all such devices depend for their successful operation upon practical application of scientific information. The foolproof cupola is a remote possibility. The weighing of air delivered to the cupola will not obviate the necessity for careful observation of melting conditions. The cupola operator must be continually checking up on his job if he is to obtain results.

The construction of the cupola and its accessories as to the intake of air is complicated and has been greatly modified. The arrangement for the outgo of the molten metal is simpler.

The opening for drawing off the molten metal is called the tap hole. This is merely a hole through the cupola shell. This opening is usually about 1 to $1\frac{1}{2}$ in. in diameter and is located at the lowest point of the sand bottom. It is part of what is known as the breast and is fully described in the

chapter on "Operation of the Cupola." Figure 60 shows a tap hole in a cupola. The iron runs through the tap hole on to the trough or spout. This extends out from the cupola and is lined with refractory material. The trough is described in the next chapter.

The slag spout is similar to the cupola spout in general form, but is smaller and is located as a rule on the back of the cupola opposite the cupola spout. It may, however, be located at any convenient point on the circumference of the cupola. Its lining is similar to that of the cupola spout. The position of the slag hole depends upon the operation of

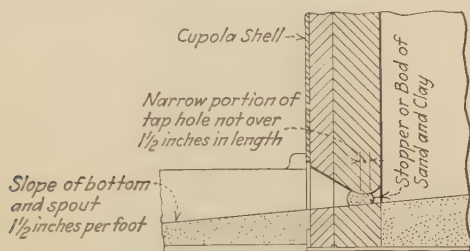


FIG. 60.—Tap hole of cupola.

the cupola. Where large heats are taken off at one time, the capacity of the cupola hearth must be increased by raising the position of both tuyeres and slag hole. For continuous operation they are placed low. Either the slag spout may be placed from 3 to 5 in. below the margin of the tuyeres, or the adjacent tuyeres are so placed that the lining is left intact some 6 in. on either side. In this case, the slag hole may safely be as high as 2 in. below the tuyere margin. If the slag hole is placed too close to the tuyeres, the blast of cold air will chill the slag sufficiently to prevent its running off.

The two bottom doors are semicircular in form and swing on hinges attached to a ring on the cupola shell. The entire weight of the charge rests on these doors which are cast iron plates. They are held in place by means of a prop which is usually a steel shaft. A few holes $\frac{1}{2}$ to 1 in. in diameter in the doors allow the gases from the bottom to escape.

The cupola is divided into five zones—the crucible or hearth, the tuyere zone, melting zone, charging zone, and the stack.

The hearth extends from the sand bottom to the bottom of the tuyeres. This is sometimes called the well because the melted iron drops down into it before being tapped out. The

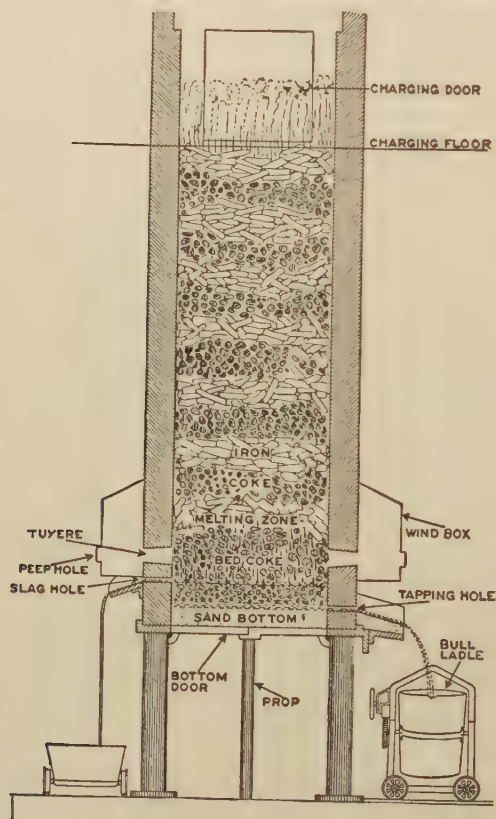


FIG. 61.—Sectional view of a cupola.

tuyere zone is the section where the blast enters and it extends from the top of the hearth to the melting zone.

The melting zone, as its name indicates, is the zone in which the melting takes place and it is the hottest part of the cupola. It extends from the tuyere zone to a point about 20 to 30 in.

above the top of the tuyeres. The exact location varies and one of the problems of the foundryman is to see that it is correct. The melting zone should not be over 8 to 12 in. in height. The position and depth of the melting zone may be learned after a heat as the cupola lining will be somewhat burned away at this point due to the action of the iron oxide on the acid lining. If the melting has not taken place in the correct location, adjustments can be made in the next heat in the height of the coke bed and the amount of coke in the charges.

The charging zone extends from the melting zone to the charging doors. The material in this zone absorbs heat thus aiding the melting process.

The stack extends from the charging doors to the top of the cupola. The general arrangement of the cupola is shown in Fig. 61 which is reproduced here by the courtesy of the publishers, Frederick A. Stokes Company, and the author.

Topical Questions

1. List three items of special knowledge which are necessary in melting but are unnecessary in molding.
2. What are the principal differences between the air furnace and cupola as used in foundries?
3. If the original 8-in. lining of a 40-in. cupola shell has been made thinner by chipping and wear until the lining averages 7 in. in thickness, what is the approximate size of the cupola?
4. Why is a double lining less likely to burn through than a single lining of equal thickness?
5. Explain the reason for one difference in the design of a cupola intended for continuous operation.
6. How near to the level of molten iron is it advisable to introduce air? What would be the result of variations in either direction?
7. Why not have the tuyere area 50 per cent of the cross-sectional area of the cupola? What is the relationship of tuyere area to the condition of lining?
8. What would be the probable effects upon the product of a cupola whose air supply is inadequate? What would be the probable effects if too much air pressure is used?
9. What, if any, is the difference between the lining of the tap hole, and spout, and of the sides of the cupola?
10. What is slag? What is likely to result if the slag spout is too far below the tuyeres? Too close?

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CHAPTER I

OPERATION OF THE CUPOLA

Before describing briefly the operation of a cupola, the student must bear in mind at all times that each cupola is an individual in itself and, therefore, must be studied, as such, in order to obtain the best results from it. Conditions arise in every foundry where one or many operations have to be varied to suit the particular cupola and the product.

As the student progresses in his shop work and becomes accustomed to cupola practice, he will undoubtedly run across one or more ideas in this chapter which would not apply in the particular foundry in which he is working. There are, however, a number of general steps in the operation of a cupola which are followed in every shop but which vary in detail. The underlying principles are the same, but the combination of principles and their application must vary with the situation. In this chapter, attention is given only to these general steps, a number of the principles involved, and a few examples of their application in certain situations.

In preparing a cupola for a heat, assuming that the cupola has been in operation previously, the first step is chipping out any cinder and slag clinging to the lining. If there are any depressions or holes in the lining, they should be daubed up with clay. Caution must be taken not to patch too thick or large as there would be danger of peeling off during the heat, with the possibility of causing the cupola to bridge over. If the hole in the lining is large, split bricks can be inserted with safety and the lining patched around them.

The bottom doors are put up and propped securely with a steel prop. The base of the prop should be placed on a flat surface, such as a casting, so that it can be pulled easily when the bottom is dropped after the heat is over.

The sand bottom is then put in. In preparing the sand for the bottom, care must be taken to assure the proper temper. It should be the same temper as molding sand. The material used is usually partially burned molding sand mixed with good molding sand. Gangway sweepings riddled through a No. 4 riddle are often used. The sand may be tempered with a little clay wash if more bond is necessary. The cracks around the cupola doors are plugged with clay.

If the sand bottom is too wet, the molten iron will boil and cause a great deal of trouble. If too dry, it will wash and the iron will melt a hole through the bottom doors. It should be carefully rammed against the lining, and care must be taken not to ram it so hard that iron will not lie on it. It should slope from the back of the cupola toward the tap hole and at the tap hole it should be on a level with the bottom of it.

Wood is placed on top of the sand bed, care being taken not to disturb the bottom. Enough kindling is put in to start the coke burning. At present the majority of foundries are using oil burners to light the cupola. These burners have proved very satisfactory and economical. When using an oil burner for lighting, a satisfactory method is to light through the breast. Long pieces of coke are selected and placed on end on the bottom so as to form an arch. This arch should extend from the breast to the center of the cupola and then branch into two arches so as to form a Y. In this way, the flame can reach through the arch and light the entire bottom of the coke bed at one time.

The cupola is now ready to light up. About 2 hours are allowed between the time of lighting and the time the wind goes on. The coke must be ignited evenly throughout the cupola so that one side will not burn through ahead of another. Two or three of the doors in the wind box are opened to allow for natural draft.

The coke bed is placed in the cupola through the charging doors. The amount of coke used on the bed is discussed in the chapter on calculation of charges. About two-thirds of the coke bed is put on at this time. When this is lit up and burning through, observation can be made as to the draft of

the cupola and as to which tuyeres can be closed up in order to regulate it better. The balance of the bed is put on just before charging.

The building of the breast, just as soon as the coke is sufficiently lighted to keep on burning properly, may be accomplished in a number of ways. One method is as follows: A round stick the size of the tap hole is laid in the bottom of the trough. Then a split brick with a hole in it is placed back of the breast next to the lining. A mixture of fire sand and fire clay is then daubed around the stick and against the split brick until the opening for the breast is completely filled up. The stick is removed and the tap hole smoothed out, enlarging it a little toward the inside of the cupola and on the outside as well. Care should be taken not to have the tap hole too long as it would be apt to freeze up. About $2\frac{1}{2}$ in. is the correct length.

The bed is allowed to burn through until it is a bright red all across the top of the coke. Then a sufficient amount of coke is placed on top of this bed to bring it to the proper height above the tuyeres and to level it off, filling holes left by burned wood. The cupola is then ready to charge.

Dr. Moldenke advises the following procedure:

On top of the bed for the first charge, it is inadvisable to use steel or very small scrap, for the dripping of the low total carbon cast iron made of the steel, as well as the too early melting of the small pieces of scrap, finds the bottom comparatively cold and promptly causes these drops to freeze on it and accumulate. It will take the molten metal of the next two or three charges to wash this accumulation of frozen iron away. The first charge of metal should none the less be of the same weight as the others; for unless the bed is unusually high, a larger first charge means cutting down the bed too deeply with resulting oxidation until the bed is built up again.

The first intermediate coke charge goes on top of the first metal charge. After this, the flux or limestone is spread evenly over the coke. This is kept about 6 in. away from the lining to save cutting this when the flux gets into the melting zone. The purpose of the limestone addition is principally to flux away the ash of the coke. A rough calculation of the amount involved with 10 per cent ash in the coke used shows the need for this. Also, the sand on the sprues and on what sand cast pig may have been used is thus taken care of.

If steel is used, this goes on first, over the coke charge with its flux cover. This should be distributed evenly over the coke, and be preferably not over 1 in. in thickness, though if a high bed is maintained throughout the heat, even heavy rail sections can be used. Very small pieces, such as punchings, should under no circumstances go into the cupola; as they roll down into the melting zone, get in front of the tuyeres before they are fully melted, and oxidize badly, with consequent bad effects on the castings made.

The pig iron to be used goes on the steel. If the steel is of several brands, each lot is spread evenly and uniformly over the whole cupola area; so that, with the scrap placed directly above and also evenly distributed, every square foot of cupola area has a uniform weight and composition of iron to be melted by the same proportion of coke directly below it. Unless this is done, the melting zone becomes uneven and dips down too low in places, bringing the melting metal into contact with free oxygen of the blast. This means local oxidation, which though distributed all through the metal in the ladle, nevertheless affects it injuriously.

The principle involved in having a column of coke, steel, pig, heavy, and then light scrap, is that steel melts at a higher temperature, pig iron takes a longer time to absorb the melting heat, and light scrap melts sooner. Thus, by virtue of their position in the ascending currents of hot gases all will melt at about the same time and run down together into the well of the cupola, with the chance that any unmelted steel will be washed away by the metal coming from directly above it. If steel were put on the top of the charge, it would simply be melted with the charge above.

The usual quantity of limestone (which should contain over 90 per cent calcium carbonate, preferably 95 per cent) is 40 lb. to the ton of metal charged. With machine cast pig iron and tumbled sprues or very clean metal going into the cupola, the limestone can be cut down to 20 lb. But when using sand cast pig iron, high ash coke, and the sprues as they come from the foundry floor, and particularly when the cupola is running continuously, 80 and even 100 lb. limestone may become necessary.

The proportion of metal and intermediate coke for usual practice, with good coke, is 10 to 1. Where over 10 per cent steel is used it must be at least 9.5 to 1. Since the new developments in high test cast iron have shown that the hotter you melt, though cooling down to normal pouring temperatures, the better the castings, it would be better to start with 9 to 1 on general principles and with high steel charges get nearer 8 to 1 in actual practice. Where very thin castings, which must stand pressure, are to be made, such as radiators

and boiler sections, it pays to go even as low as 7 to 1. In fact, one has to do this or get heavy discounts in the castings made.

The wind is then put on, and the cupola starts its melting process. It is well to note the exact time when the blast is put on, as it is important to learn the length of time before the first iron is melted. In case the tap hole is left open, the iron issues from it and runs strong enough to go over the spout and into the ladle or on the floor. This should be from 8 to 12 min., preferably 10 min. If the tap hole is kept closed, the only way to know if the bed was of the proper height is to observe through the peep holes when the first iron begins to drop past them. This iron should not be seen before 6 min. if no very small scrap was used on the first charge, as this light scrap is deceptive. If the iron begins to drop sooner than this, it shows that the bed was too low.

The melting rate of the cupola being known, the cupola is tapped when the well is considered full enough for this to be done. If the well is allowed to fill up to the tuyeres (the slag hole being shut for the first part of the heat) the rising iron may be seen through the peep holes. This is very risky, and it is preferable to have the metal out before the iron has risen this high. Tapping is accomplished by digging out the clay plug used to close up the tap hole in the first place.

When enough iron has been drawn off or slag commences to show, the cupola is plugged by means of a bod which is a cone-shaped lump of clay attached to a bod stick, either wood or iron. In placing the bod in the tap hole, care must be taken to come down on the stream at a sharp angle and not try to go directly against it. The bod must be securely placed in the tap hole so that it will remain in place.

If the breast freezes, the best way to free it from the frozen iron is to melt it out with an acetylene torch. This is less injurious to the breast than knocking it out with a heavy bar, and is much quicker.

As the iron melts, more charges are put in until sufficient for the day's heat have been added. The cupola should be kept full to the charging doors during melting. The operation of tapping out is repeated until all the iron has been melted. The wind is turned off a few minutes before the cupola is empty so the lining will not be burned out unnecessarily.

After the cupola is drained, the prop is pulled allowing the bottom to drop. The next morning the cupola helper sepa-

rates the good coke, slag, and iron. The coke can be mixed in small proportions with new coke and used again. The iron is usually figured in as return iron unless it is in the form of unmelted pig. If in the latter form, it can be used as pig iron. Foundries having large heats usually have a magnetic separator to separate the iron from the coke and slag. In this way there is very little waste in the drop.

Changes in the operation of the cupola are being made as the result of the development of new types of construction, different methods of control, new materials, and varied uses of familiar materials. Any new method involves much experimentation, and the results, when successful, may be of more value in the operation of one type of cupola than another.

Two of these methods relating to fuel involve the development of equipment for the application of ideas which have long been considered by foundrymen. One is the use of powdered coal which is burned outside of the cupola, and the hot gases produced in its combustion are introduced through the tuyeres. Another is a method of using the hot cupola gases. The heat produced in the combustion of the carbon monoxide, and of other combustible gases from the stack, is used to preheat the blast.

Topical Questions

1. If steel is used in the charge, why is it placed in the cupola first?
2. How should the breast be dried out before the tap hole is ready for the heat? Explain in detail.
3. If you were melting 1,000-lb. charges, how much coke would you use in the coke charges?
4. Under what operating conditions is the slag hole used? When it is used, at what time in the heat is it usually opened?
5. Why should pig iron be broken before charging? How large may the pieces be?
6. What is the advantage of a mixture of fire sand and fire clay in the daubing around the stick when putting in the breast?
7. Explain the disadvantages of a too wet bottom; of a too dry bottom.
8. What may happen if the bottom is too thick? Too thin?
9. What is meant by weak sand for cupola bottom? Why does a clay wash improve it?
10. Explain the choice of refractory material used in finishing a tap hole.

11. What is the reason for forming a tap hole around a rod?
12. Why does not the pressure of molten metal push the clay stopper out of the tap hole?
13. Explain the result of too hard ramming on the lining of the cupola.
14. From this chapter and your observation and experience, list ten errors that are sometimes made in the operation of a cupola. After each, state the correct practice and the reason.

Text References

1. MOLDENKE, RICHARD, "Principles of Iron Founding," pp. 377-392.
2. SPRING, LAVERNE W., "Non-technical Chats on Iron and Steel," 2d Ed., 1927, pp. 170-177.

CHAPTER LI

CALCULATING MIXTURES

To understand the calculating of mixtures, it is first necessary to know just what happens to the different elements in the cupola as the iron is being melted, so such allowances as may be necessary can be made in order that the product may be close to the calculated mixture. This will be a brief review of the effects of the different elements upon iron, a subject with which the foundryman must be quite familiar before he is ready to use this knowledge in the calculation of a mixture of iron.

Silicon.—Each time iron is melted either as pig iron, return iron, or foreign scrap, some of the silicon content is lost by oxidation. This amount has been carefully computed many times, and the average has been found to be about 10 per cent of the contained silicon. By subtracting 0.25 from the calculated mixture the silicon content of the product is found. In other words, due to oxidation in the cupola, the calculated mixture must contain 0.25 more silicon than desired in the product. In practice, 25 points of silicon are added even if the percentage desired in the product is less than 2.50. Thus if 1.75 per cent silicon is wanted, $1.75 + .25$ or 2.00 will be obtained in the mixture. This calculation can be done mentally if the foundryman keeps in mind that the per cent of an element is its number of pounds per hundred, and the weight per ton in pounds is 20 times the per cent. Thus 2.00 per cent of silicon desired in the mixture means 20×2.00 or 40 lb. in a 2,000-lb. charge.

Sulphur.—The sulphur content usually comes next in calculation for the reason of its influence in the mixture. Because the iron in the cupola comes in direct contact with the fuel used in melting (which always contains sulphur) and because iron has a strong affinity for sulphur, each time iron

is melted, sulphur is added. The amount of this addition has been found to be 0.02 under ordinary melting practice. If the coke is poor and high in sulphur, this will be more. When the coke is normal and the cupola operating as average, the product will contain 0.02 more sulphur than will show in the calculated mixture so this is added to each calculation to arrive at the sulphur content of the product.

Manganese.—This element oxidizes quite as readily as does silicon so it is necessary to figure manganese in the mixture 0.15 higher than is wanted in the product.

Phosphorus.—Some foundrymen calculate silicon first, then phosphorus, and next manganese. The melting process in the cupola does not reduce the amount of phosphorus by oxidation or by carrying this element into the slag; neither is the amount increased from the ingredients in the charge other than the pig iron and scrap in which the amount is known. The phosphorus in the product is sometimes figured exactly as in the mixture. In more accurate calculations, account is taken of the effect of concentration through melting loss. An increase of 0.03 to 0.04 per cent of phosphorus may be obtained in the product and the charge may be calculated accordingly.

Total Carbon.—Due to the fact that the melted iron comes in direct contact with the coke, carbon will be absorbed from the coke by the iron. This is especially true if the mixture contains any steel, this material being low in carbon. A high percentage of steel, therefore, means lower total carbon.

Now that what happens to the different elements when iron is melted in the cupola has been explained, the different materials will be considered which must be used daily to keep the stock on an even basis, that is, no accumulations.

Domestic Scrap.—This name applies to all return iron; that is, sprues and gates, contents of the pig bed, and drop and bad castings that are returned daily. This amount should be used each day and not allowed to pile up. The only exception is when the product is way off; then a new start should be made leaving out the domestic scrap entirely until the cupola is running right again. It costs money to handle

material, and one handling of scrap is all that is necessary if it is used each day.

Let it be assumed that this amounts to 500 lb. per charge of 2,000 lb. This will vary according to the product being made, and how close the iron is figured.

Steel Scrap.—Most foundries are now using some steel scrap in their mixture, varying from 5 to 25 per cent and even higher for special purposes. It is much safer to use short length rails or some such material than to buy small miscellaneous steel for the reason that the latter material is apt to contain much special mixture steel of unknown contents. The addition of steel reduces all the elements—silicon, sulphur, manganese, phosphorus, and carbon. Foundry experience proves that if much steel scrap is used, a higher amount of manganese is necessary to insure good castings.

Let it be assumed that 10 per cent of steel is used in the mixture. This would give 200 lb. of steel for each charge of 2,000 lb.

Pig Iron and Foreign Scrap.—Foundries use from 40 per cent scrap and 60 per cent pig iron to 50 per cent scrap and 50 per cent pig iron depending on the product being made. Due to the fact the furnaces are using so much scrap to fatten their ores, it is safer to figure 40 per cent scrap and 60 per cent pig iron. Machinery scrap is the best foreign kind used. Each piece will then show some signs of having been machined and hence is somewhat near what the product is to be. Under whatever specifications pig irons are purchased, each carload should be used under its actual analysis, whether this be furnished by the furnace or by the foundry itself. It is also well to have some high manganese (at least 4.00 per cent Mn.) and high silicon (5.00 to 12.00 per cent Si.) in the yards for purposes of doctoring only.

Let it be assumed that the mixture is to be 40 to 60. It will be necessary to have 1,200 lb. pig iron and 800 lb. of scrap. Five hundred pounds domestic scrap and 200 lb. steel rails have already been figured to each ton of charge, so 100 lb. only of foreign scrap can be added to each charge of 2,000 lb.

Let it be assumed that from these irons is to be produced a product having as near as possible silicon 2.00, sulphur 0.07

or under, manganese 0.70, phosphorus 0.50. Taking care of the changes in the cupola the calculated mixture should contain: Silicon $2.00 + 0.25 = 2.25$, sulphur 0.07 or under $- 0.02 = 0.05$ or under, manganese $0.70 + 0.15 = 0.85$, phosphorus 0.50. Changing the percentage to pounds by multiplying the percentage or amount in 100 lb. by 20, the number of hundreds in a charge of 2,000 lb., it is seen that in each 2,000 lb. of metal is needed: Silicon 45 lb., sulphur 1 lb. or under, manganese 17 lb. phosphorus 10 lb.

These requirements may be summarized in a table showing how the pounds in the mixture are obtained from the percentages required in the product.

Elements	Product, per cent	Mixture, per cent	Mixture, pounds
Silicon.....	2.00	2.25	45
Sulphur.....	0.07 or less	0.05 or less	1 or less
Manganese.....	0.70	0.85	17
Phosphorus.....	0.50	0.50	10

The information which the foundryman has in regard to the composition of his irons is usually kept on cards. These figures can be readily transferred to one of the various blank forms now in quite general use for the calculation of mixtures. The form used by Charles C. Kawin Company is shown.

The first trial mixture can now be calculated to see how near it comes to the ideal mixture, and the changes which must be made to improve it.

The rule is to multiply the weight of each kind of material by the percentage (which is the same amount of the element contained in 100 lb.), and divide the total weight of each element thus obtained by the weight of each charge to get the percentage of the element in the mixture. By changing the amount of the different irons used, adjustment can be made to get very close to any regular mixture.

The pig and scrap available have the composition given below. The pig iron is referred to by number for convenience, but it should be remembered that the actual composition of iron must always be considered.

Beginning with the silicon, and the three kinds of scrap it has been planned to use (domestic scrap, steel and foreign scrap), the proportions are:

Constituents	Pounds, scrap	Per cent, silicon	Pounds, silicon
Domestic scrap.....	500	2.00	10.00
Foreign scrap.....	100	1.90	1.9
Steel rails.....	200	0.10	0.2
	800		<u>12.10</u>

The percentage of silicon in 800 lb. of these three irons = $12.1 \div 800 = 1.5$ which is far below the 2.25 desired in the mixture.

If possible, the use of expensive high-silicon iron should be avoided, so this 1.5 per cent of silicon in the scrap should be raised to 2.25 by means of pig alone. Only experience in figuring this many times will enable a foundryman to know at a glance whether he needs to use special irons. At this time, the beginner must go through with his estimate in detail.

Looking at the silicon content of the pigs, it is noted that Nos. 3 and 4 are far below requirements, and No. 2 has so little above the amount needed that it could not pull up the silicon content of the scrap. In fact, the average silicon in these four kinds of pig is only 2.175 per cent. Number 1 is the only pig with silicon high enough to materially raise this element in the mixture to the amount wanted. With experience, a foundryman learns to estimate how much effect on the silicon in a 2,000-lb. charge can be expected from 1,200 lb. of iron with 0.7 per cent more than needed (2.95 and 2.25).

Let the effect of using only No. 1 pig to supplement the three kinds of scrap be noted. The figures just obtained as to scrap will be used.

Constituents	Pounds, material	Per cent, silicon	Pounds, silicon
Scrap (three kinds).....	800	1.5	12.1
No. 1 iron.....	<u>1,200</u>	2.95	<u>35.4</u>
	2,000		<u>47.5</u>

This gives 47.5 lb. of silicon. $47.5 \div 2,000 = 2.37$ per cent which is only a little more silicon than needed. This means that it would take nearly 1,200 lb. of No. 1 pig to get the silicon from this source. This would be expensive, the sulphur would be needlessly low, and the manganese undesirably low. So the conclusion is reached (which later may be achieved at a glance) that some of the 5.00 per cent silicon iron must be used to bring up the silicon in the scrap in order to use cheaper pig. Let 100 lb. be used in the first trial mixture.

Just here one might as well look ahead and see if any of the high manganese is needed. Since not one of the other irons contains 0.85 per cent manganese, the amount wanted, and several contain much less, a little of this special iron, also, will be needed. Let 50 pounds be added to the trial mixture.

The figures in the table below are in a form commonly used in calculating mixtures. The crossing out of figures and adding others above them was done later as the need for changing the proportions was found. The usual method is to erase the figures to be changed, but the originals were left in this case to show these changes.

Car number and grade	Analysis, per cent				Weight, pounds				
	Silicon	Sulphur	Phosphorus	Manganese	Total	Silicon	Sulphur	Phosphorus	Manganese
N. Y. C. 2810 No. 1.....	2.95	0.03	0.55	0.50	500	14.75	0.15	2.75	2.50
					~~400~~	~~11.80~~	~~0.12~~	~~2.20~~	~~2.00~~
L. & N. 3876 No. 2.....	2.35	0.04	0.65	0.70	300	7.05	0.12	1.95	2.10
					~~400~~	~~9.40~~	~~0.16~~	~~2.60~~	~~2.80~~
C. M. & S. T. P. 4732 No. 3	1.90	0.045	0.72	0.50	100	1.90	0.045	0.72	0.50
					100	1.50	0.06	0.75	0.50
P. R. R. 5860 No. 4.....	1.50	0.06	0.75	0.50	~~150~~	~~2.25~~	~~0.09~~	~~1.125~~	~~0.75~~
Domestic scrap.....	2.00	0.07	0.50	0.70	500	10.00	0.35	2.50	3.50
Foreign scrap.....	1.90	0.10	0.50	0.65	100	1.90	0.10	0.50	0.65
Steel rails.....	.10	0.07	0.10	0.60	200	0.20	0.14	0.20	1.20
High silicon.....	5.00	0.03	0.06	0.38	100	5.00	0.03	0.06	0.38
					100	2.30	0.035	0.05	5.50
High manganese.....	2.30	0.035	0.05	5.50	50	~~1.15~~	~~0.017~~	~~0.025~~	~~2.75~~
						44.60			
						~~44.20~~	1.03	9.48	16.83
Pounds.....					2,000	~~43.60~~	~~1.042~~	~~9.83~~	~~14.33~~
						2.23			
						~~2.21~~	0.051	0.474	0.84
Per cent.....						~~2.13~~	~~0.052~~	~~0.49~~	~~0.71~~

The silicon is found to be a little too low, 2.18 instead of 2.25. Let the No. 1 iron be raised 100 lb. and decrease No. 2 by this amount. This gives 44.2 lb. and 2.21 per cent of silicon. This is a little low but the other elements in the trial mixture will be calculated so as to get a suggestion of where to change it.

This gives first, for sulphur, 1.042 lb. and 0.052 per cent, which is barely within the requirements.

Phosphorus is figured next; 9.83 lb. and 0.49 per cent are found, which are satisfactory.

The manganese is found to be 14.33 lb. and 0.71 per cent which is entirely too low. The high manganese iron is the only cure for this and as it is relatively high in silicon it will help here also. Changing the 50 lb. to 100 and taking this from iron No. 4 gives 16.83 lb. or 0.84 per cent manganese which is acceptable.

Calculating the entire mixture with these changes shows silicon 2.23, sulphur 0.051, phosphorus 0.474, and manganese 0.84, so this mixture may be kept until prices, or availability of raw material, or qualities of product require a change.

There are two roads to failure in operating a foundry, which depend upon entirely opposite views in the calculating of mixtures.

One is to insist upon only the high-grade materials which are known to give good results, while the enterprising and well trained competitor gets just as good results with some of the cheaper materials. A fair selling price is essential in a market as competitive as that for castings. The change to a new mix, like the use of steel scrap, which has become common practice lately, will make work for the foundryman, but keeping down costs in production requires a man to be constantly on the alert for new methods and materials. But if he thinks of costs and overlooks quality, the sale of his product is injured or the scrap becomes so high that costs begin to mount.

Topical Questions

1. Why is iron not purchased with more silicon than needed? With less?

2. What two articles are sometimes used as medicine in the foundry? When is each needed?
3. When, if ever, is the use of these materials justified?
4. What are three possible sources of loss from allowing scrap to accumulate?
5. When must the phosphorus be figured next to the silicon?
6. Why does a manufacturer of light castings usually buy very little scrap?
7. Prepare a table in the form shown below and indicate on it changes in the mixture which foundrymen make, with materials mentioned in this chapter, in order to obtain desired results. The table reads: When a mixture is too high in silicon, a cheaper pig iron may be used, or steel may be added.

CHANGES IN MATERIALS IN MIXTURE WHEN AN ELEMENT IS:
Too HIGH Too LOW

Silicon:	1. Use cheaper pig, etc.
	2. Add steel
Manganese:	1.
	2.
Phosphorus:	1.
	2.
Sulphur:	1.
	2.

8. What is a safe middle course for a foundryman to follow in avoiding changes of materials that may hurt his product, and yet making any changes that will lower the cost of production? Give an illustration.

The Mixture for High Test Cast Iron

NOTE: High test iron has continued to attract attention. No subject in recent years has interested foundrymen more than this. Its possibilities are so great and its development so important that it was thought best to include a brief discussion here. With this in mind, Dr. Moldenke was prevailed upon to prepare the following statement.—THE EDITOR.

Recently there have been extremely important developments in the gray cast-iron industry. In the course of some highly theoretical studies on overcoming the "growth" of cast iron under alternate heating and cooling, the German discovery was made that all molten gray iron under ordinary degrees of superheat retained minute points of graphite (called nuclei) in suspension, all the rest of the original graphite in the mixture having been converted to combined carbon in the melting. During the usual cooling process, or while pouring into molds, these microscopic graphite nuclei form the starting points of the large crystals which we know in ordinary cast iron.

It was further discovered that if such molten gray iron under ordinary degrees of superheat were given still higher temperatures (either in furnace or electrically), these graphite nuclei would gradually dissolve and disappear. The final disappearance of all graphite takes place at perhaps 2900 to 3000° F. and can be attained in the cupola only when practically all-steel scrap mixtures with an abundance of fuel for melting are used. Such tremendously superheated metal is then allowed to cool in the ladle, care being taken not to hasten this by throwing in scrap (which would introduce graphite) and the molds poured off when ordinary pouring temperatures have been reached (approximately 2450° F.). There being no graphite nuclei to start large crystals, all the graphite formed when the metal sets is in very small crystals, and both tensile and transverse strength of the iron rises correspondingly.

The best results are obtained with all-steel scrap to which enough ferrosilicon and ferromanganese have been added to give the composition indicated below. This is best done by mixing the ferroalloys with about 15 per cent cement to form briquettes, letting these set hard and then drying thoroughly. They will then descend into the melting zone intact and give full value of silicon and manganese to the resulting metal. Ferronickel and other metals can also be put into the cupola this way, and work very well if very evenly distributed over the entire cupola area. Enough coke must be charged to give the highest temperatures attainable, and the carbon of the resulting metal is taken from this fuel. A high bed in the first place, and a ratio of 7:1, shaded down to 8:1 as the heat progresses, will give enough carbon to turn the steel charged into a "synthetic" cast iron with a strength of up to 55,000 lb. per square inch. With 1.50 to 2.00 nickel added this can be pushed up close to 60,000 lb.

The composition of the best of this high test cast iron, without nickel addition, is as follows: Total carbon, 2.75; silicon, 2.75; manganese 1.00; sulphur and phosphorus, each about 0.06, or whatever melting steel will bring as these elements do not run much over 0.05 in the first place. When using lower percentage steel mixtures, the results will naturally not be as high, but superheating them intensely will none the less almost double the results obtained over ordinary practice. If the silicon is held down to 1.75, the highly superheated metal will require annealing to machine well. Doing this for 6 hours at 1450° F. will result in a cast iron which can be bent and will elongate somewhat. This metal is valuable for heavy sectioned castings, as these will practically anneal themselves if left covered with sand overnight.

The lesson to be learned from the above is that it pays to be generous with coke in cupola melting, and the higher the degree of superheat attained in melting for the same pouring temperature, the stronger and better your castings.

Foundry Problems

If the student can do so, it would be well for him to make out a table with the composition of the iron available in a foundry with which he is acquainted. Then he should make a statement of the composition required in the product and of the mixture he desires to make. This material should be used in all of the following problems. Otherwise, the materials and their composition given in this chapter should be used as a basis for the calculation of mixtures in the following problems:

1. The yardman needs the space where car number N. Y. C. 2810 is piled. Figure a mixture using as much of this iron as is safe.

2. The purchasing agent is able to get a very good price on some iron with the composition Si, 3.25; S, 0.12; Phos, 0.60; Mn, 0.45. (a) What are all the possible advantages of purchasing this iron? (b) What limits should be observed in using this or any other iron? (c) Calculate a mixture using this iron.

3. When cars numbered 5860 and 4732 run out, new cars are purchased with a different composition. (See previous statement of composition of iron in cars mentioned in illustration.) In place of car number 5860 is one with iron having Si, 1.65; S, 0.068; Phos, 0.70; and Mn, 0.50. In place of car number 4732 is one with iron having Si, 2.00; S, 0.055; Phos, 0.70; Mn, 0.55. Calculate the mixture. Unless the student takes a product within his experience, all problems should be figured to give the product used in the example.

4. Make the necessary calculation to show how many sash weights weighing 7 or 8 lb. each can be added to a ton charge without making any appreciable difference in the mixture.

5. Get local prices to show the cost per pound of iron in the castings made with the four different mixtures you have calculated.

Text References

1. MOLDENKE, RICHARD, "Principles of Iron Founding," "Mixture-making," Chap. XII.

2. SPRING, LAVERNE W., "Non-technical Chats on Iron and Steel," 2d Ed., 1927, pp. 160-164, 168-170, 198-199.

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CHAPTER LII

CHARGING THE CUPOLA

An important thing to keep in mind at all times in figuring out the amount of coke to use on the bed and between charges, is that coke must be considered on a volume basis and not a pound basis. The hottest place in the cupola is situated about 28 in. above the top of the tuyeres and, if good melting is done, the iron must be kept at just that point all through the heat. If the coke is a light coke, it will take a less number of pounds to keep the stock at that point than if heavy coke is used. A good way to keep the proper depth of bed at all times, regardless of variations in the coke, is to have a measuring stick made, which will hang from the charging door opening, and be sure the coke bed comes up to the bottom of the stick every day. This will insure the proper depth of bed whether the coke is wet or dry, light or heavy.

The melting zone can be seen in the cupola lining for the lining will cut out at this point and this will show after one or two heats.

The proper height of bed can also be estimated by the time it takes for iron to come down after the blast is put on. It should be noted that this is given as a method of estimating rather than of accurately determining the height of the bed. Wherever estimates are depended upon, an opportunity exists for scientific development. If the bed is just right, melted iron will run in a little stream out of the spout in 8 to 12 min. after the blast is put on. If it comes in less time, the bed is too low and should be raised slightly. If it takes longer, the bed should be lowered slightly. Having once determined the height, have a measuring stick made and then measure the height every day.

This height should be maintained all through the heat as closely as possible. As one charge melts, the bed will go

down a little; then the coke put on between charges raises the bed again, and this is kept up until sufficient iron has been melted.

This accounts for the change which has taken place in the last few years in reducing the amount of iron in each charge. If only a small charge is used, the bed will burn very little before its height is restored. While if large charges are used, the bed is constantly being raised and lowered too much. More and smaller charges will give best melting conditions but with a little higher ratio of coke to iron.

The amount of coke used between charges is about 10 per cent of the weight of the iron charge, that is, if 1,000-lb. iron charges are used 100 lb. of coke between charges will be found to be about right.

The amount of iron and coke in charges is always a question for adjustment according to furnace conditions and requirements of different situations. One thing is certain, and this the young foundryman should keep in mind. Hot iron is the aim and as a general rule, the hotter the better. While there is the possibility of over oxidation under certain conditions, this is not merely the result of high temperature. It is good practice to keep the iron in the cupola as hot as possible. Since large charges of iron must absorb much heat with consequent lowering of cupola temperature, it is evident that light, frequent charges would be desirable. But it is impracticable to reduce charges of iron to sizes where their temperature reducing effect would be ideal. A compromise, therefore, as near the ideal as is practicable must be effected.

The manufacturers of cupolas have found it necessary to furnish data sheets in which suggested charges are fixed arbitrarily. No claim is made as to their dependability under all circumstances; hence students should meet each new situation in the light of present conditions.

When the blast is put on and the iron begins to melt, charges are added so as to keep the cupola full up to the doors all the time, until all iron is charged.

When all the iron is melted, the blast should be shut off to save cutting the lining, and the bottom dropped. The last two lots of coke can be cut some, as everything

is hot and the iron will melt just as well with a little saving of coke.

Mechanical Charging.—For many years progressive foundrymen have endeavored to improve methods of charging cupolas by means of mechanical devices. Hand charging is, of necessity, more or less inefficient, and in common with all inefficient methods results in undue expenditure of human energy as compared with mechanical charging. Mechanical charging of cupolas is just another illustration of the fact



FIG. 62.—View of cupola charger about to charge.

that increased efficiency through the use of labor-saving equipment saves not only through reduction of waste and labor costs, but saves the workman as well.

Frequently in hand charging, men, in order to avoid the heat, will stand far back from the charging door when shoveling in coke. The coke strikes the lining on the far side and rebounds to the near side of the cupola where it piles up to form an incline down which the pig iron and scrap will slide to fill the pocket against the back lining. This has a tendency to hammer out the lining at the back and manifestly interferes with proper melting conditions through faulty distribution.

There are several methods of mechanical charging, ranging from tilting devices which dump the charges into the charging door to buckets with bottom doors, which may be opened after the bucket has been moved into the cupola by means of a crane.

A more detailed discussion of mechanical chargers is to be found in Moldenke's "Principles of Iron Founding," pages 405-409. This discussion is of interest because it calls attention both to the correctness of principle possible in these mechanical devices and the inefficiency of the equipment in which these principles are violated.

Topical Questions

1. What practical difficulties may occur if a foundryman begins to use a lighter coke and uses the same weight on the bed and in the charges which gave satisfaction with the heavier coke? Explain.
2. What difficulties may occur if a heavier coke is used and the weight not changed? Explain.
3. How much may a bushel of coke vary in weight? What is the reason for this difference?
4. Can the cutting of the cupola lining at the melting zone ever be reduced? If so, when and how?
5. What will be the effect of the addition of 10 in. to the normal height of the coke bed? When may it be desirable to have the coke bed this high? Why?
6. Make a comparison of the saving in more and smaller charges and in low ratio of coke to iron. That is, what is saved and at what cost, in each case, and which is the better economy?
7. Give reasons for the order of charging steel, pig iron and scrap.
8. Explain how the arrangement of steel, pig iron, and scrap described in this chapter is of value in the protection of the quality of castings.

Text References

1. MOLDENKE, RICHARD, "Principles of Iron Founding," pp. 222, 388-400, 405-409.
2. SPRING, LAVERNE W., "Non-technical Chats on Iron and Steel," 2d Ed., 1927, pp. 171-176.

PART X

FOUNDRY SANDS

The nine chapters of this part were prepared by Mr. A. A. Grubb, Director of Laboratories, Ohio Brass Company, Mansfield, Ohio. Valuable assistance in the way of illustrations, data and other information and in reviewing was rendered by Messrs. R. F. Harrington, Hunt-Spiller Manufacturing Corporation; H. W. Dietert, United States Radiator Corporation; E. W. Campion, Buckeye Steel Castings Company; E. R. Young, Detroit Steel Casting Company; Dr. H. Ries, Department of Geology, Cornell University; National Engineering Company; and coworkers of the Ohio Brass Company.

CHAPTER LIII

COMPOSITION AND PARTICLE SIZE

Molding sands have certain properties which determine their suitability for various kinds of molds and castings. The working properties are determined to an extent by the chemical composition of the sand and in a larger measure by the size, shape and arrangement of the grain and clay particles.

Chemical Composition.—Chemical analysis shows the following substances in molding sands: silica, alumina, iron oxide, lime, magnesia, alkalies (sodium and potassium oxides), combined water, organic material, and possibly a few other substances in small quantities. Usually these materials are not actually found as such; they are generally found in more or less complex combinations, such as the minerals, quartz, feldspar, mica, etc. Combined water is the water which is in such close chemical union with the other materials that it is not evaporated off at 212° F. Combined water and organic material are usually measured together, when analyzing a sand, by drying it at 212° F., weighing out a portion very accurately, heating it to a bright red heat and then weighing again. The percentage loss in weight is called “loss on ignition.” Sands which contain lime in the form of carbonates give off gas when muriatic (hydrochloric) gas is poured on them.

Physical properties depend so much on the actual mineral combinations that a chemical analysis must be interpreted with great care. The following general statements will be of help.

High silica sands are usually resistant to heat. While pure alumina is even more refractory, many of the mineral combinations in which it is found are much less refractory than silica. Iron compounds are usually red or brown, especially after heating; they are not highly refractory but

are usually more plastic and also promote peeling qualities of the sand. Lime and the other alkalies are powerful fluxes and reduce refractoriness. Magnesia is a flux but is less effective than lime. Lime, magnesia, and the other alkalies are considered impurities. Combined water and organic material promote bond strength. High loss on ignition may indicate low durability; that is, bond of short life. On the other hand, finely divided organic matter improves casting surfaces; it tends to provide a reducing atmosphere and improves peeling qualities. For this reason, flour is sometimes dusted on mold surfaces, or finely powdered coal, commonly called "sea coal," is mixed with heap sand.

Grain Fineness and Clay.—The particles of sand range in size from about an eighth to a hundred thousandth of an inch or less in diameter. Water in proper quantity, not too much or too little, causes particles to stick together, and the smaller the particles, the better do they stick. The term "clay" is applied to those particles which are less than about a thousandth of an inch in diameter. Even in clay the particles differ widely in size, the smaller they are the more sticky they are. The very smallest particles cling to each other and to larger particles, like glue. Such tiny particles are called colloids or colloidal material. Such material is very absorptive; it takes up great quantities of water, oil, or dyes. When dried, it becomes hard and strong like Portland cement. Bentonite is a highly colloidal clay that is finding wide use in bonding sands.

The word "texture" is also used in speaking of particle size. Sands of fine texture are necessary in order to make smooth mold surfaces and smooth castings.

Sands are tested for particle size by three tests—namely, sieve, clay, and dye-adsorption tests. Clay is separated by agitating a weighed sample of dry sand in a quart fruit jar half full of water containing a little caustic soda, filling the jar with water, allowing it to settle for 5 min., and then siphoning off the water and clay which failed to settle. This is repeated until the water is clear after settling 5 min. The remaining sand is filtered out, dried, and weighed. The difference between this weight and that of the original sample,

is clay and can be calculated in per cent. The sand grain from which the clay has been removed is passed through sieves of various meshes and the weight of that caught on

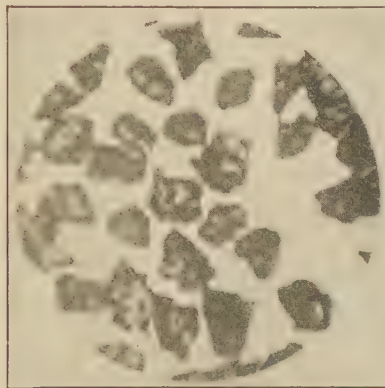


FIG. 63.—Angular grains.

each sieve is determined. The “grain fineness number” is the number of mesh per inch of that sieve which would just

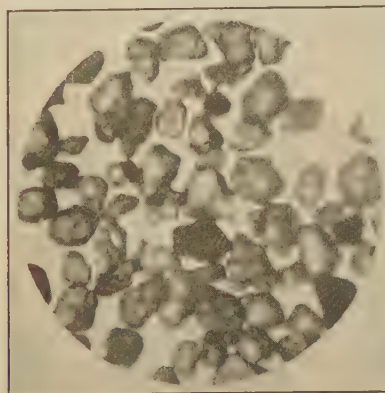


FIG. 64.—Subangular grains.

pass the sand grains if they were averaged in size. It can be calculated from the sieve data. (See “Standard and Tentatively Adopted Methods of Testing and Grading Foundry

Sands," published by The American Foundrymen's Association, Marquette Bldg., Chicago, Ill., for complete directions for testing and grading sand.)

Foundry sands are graded on the basis of grain fineness and clay content. Grain fineness is designated by numbers 1 to 10, the higher numbers representing the coarse sands; clay content is designated by the letters *A* to *J*, *J* representing the highest clay content.

No method for directly measuring the colloidal material in sand is in general use. Colloids are great absorbers of

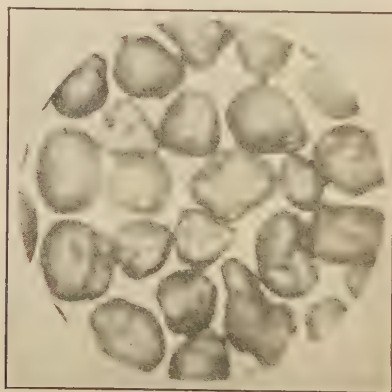


FIG. 65.—Round grains.

dyes, however, so the quantity of crystal violet dye absorbed (or adsorbed) may be taken as a measure of the colloid content of sands for purposes of comparison.

Grain Shape.—Grains of sand range in shape from round to very angular or even plate-like bodies. The terms "angular," "subangular," and "round" are used to describe them. Figures 63, 64, and 65 illustrate these three grain shapes. Number 63 is composed largely of angular grains, No. 64 of subangular grains, while No. 65 is considered a round grained sand, though it actually contains many grains that are far from spherical in shape. Angular grains tend to fuse together more readily and are not so easily bonded as subangular or round grains.

Topical Questions

1. A steel facing sand forms very hard cakes or lumps next to the casting. What is the probable cause?
2. What would roots in new sand indicate? Under what conditions would they be objectionable? When not objectionable?
3. Describe the grain size and grain distribution of a sand that would be very open and yet of high bond strength.
4. It is desirable that sand in a furnace bottom should fuse together slightly so as to form a solid one-piece bottom. Describe a sand suitable for such a purpose.

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6. RIES, H., "Clays—Occurrence, Properties and Uses," Chap. III; John Wiley and Sons.
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CHAPTER LIV

MOLDING PROPERTIES

The satisfactory use of heap sand depends on certain properties which, because of their *direct* relation to the making of good molds and castings, are called *molding properties*.

Resistance to Heat.—Heat affects sand in at least three ways:

1. It burns (oxidizes) organic matter, destroying its bonding value.

2. It drives out not only the moisture, or the water used in tempering the sand, but also the combined water; this water cannot be replaced by retempering the sand.

3. It fuses particles of sand together and on to the casting.

It has the general effect of destroying the bond, probably due to a combination of the three above mentioned effects. By driving out the combined water and by fusing the colloids together into larger particles, their sticky nature is destroyed.

The temperature at which sand particles fuse together is determined by their size as well as by their composition; the smaller the particle the lower the temperature at which they fuse or “sinter.”

The fusion temperature of sand as a whole (not the individual particles) is measured by forming it into a cone, and heating it in a high temperature furnace along side other cones, the fusion temperatures of which are known (Segar cones). A sintering test devised at the United States Bureau of Standards measures the softening point of the individual particles; the temperature at which they fuse to a platinum ribbon, heated by an electric current and resting across a specimen of sand, is observed in this test.

Plasticity, Mobility.—While these two terms do not mean the same thing, they are used to describe the velvety feel, yielding quality, and flowing quality recognized in good heap

sand as contrasted with the harsh feel of poor sand. Molding sand is by no means as plastic as clay but must have a certain degree of plasticity in order to work well. The term "mobility" refers particularly to the flowing quality of a sand; does

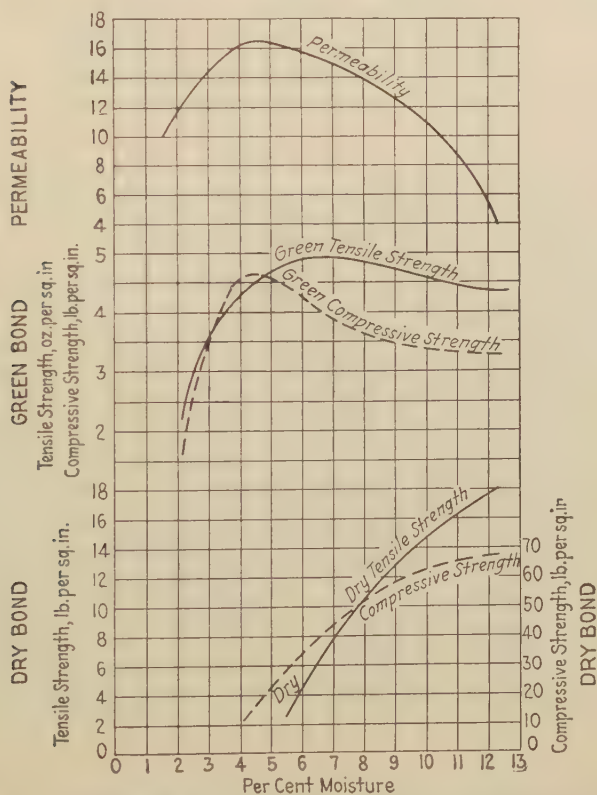


CHART I.—Permeability, green bond and dry bond of a representative brass sand at various moisture contents.

it flow against the sides of a pattern well, without excessive ramming and tucking?

While not fully understood, these properties seem to be closely related to clay and colloid content. Sands containing the proper amount of clay, particularly colloidal clay, well distributed over the surfaces of the grains, are more plastic and more mobile than those containing too little or too much

clay; too little such clay results in a harsh sand, too much produces a heavy, gummy sand that cannot be rammed against the mold without great effort. Sands of proper plasticity are not so apt to ram off or strain.

Bond Strength.—Molding sand must cling together with sufficient strength to enable the mold to retain the shape of the pattern even when molten metal flows against it with considerable force. Weak sands require the excessive use of bars and gagers to hold them in place; they result in mold

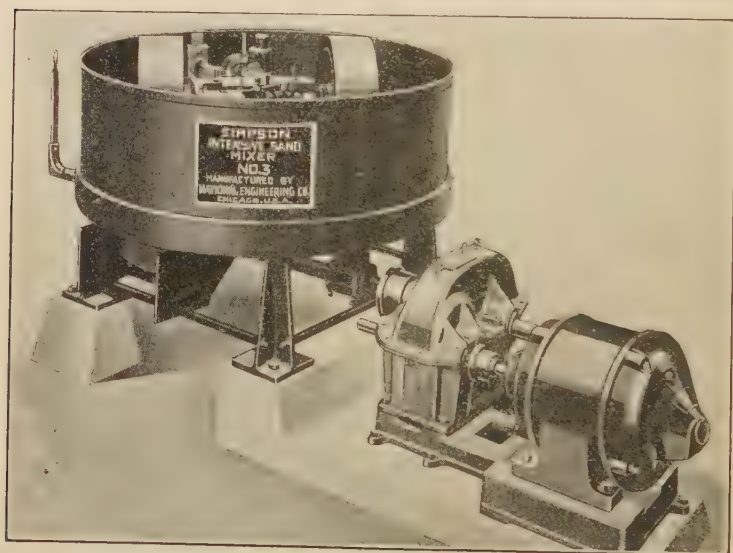


FIG. 66.—Sand mixer of the muller type. (Courtesy of National Engineering Company.)

drops, stickers, and in strained or cracked molds. Weak sands cut and wash, producing dirty or rough castings. On the other hand, a very strong sand is less mobile, so requires much labor to tuck into corners and ram properly.

Sand which is too dry does not ram up into strong molds or cores; with increased moisture content, the green bond strength of the rammed mold or core increases to a maximum value and then decreases. Chart I shows the variation in physical properties with moisture content of a representative brass sand of rather fine texture.

Wet sand flows well and packs closely but is weak. Fine sands and sands of a wide variety of grain sizes usually have higher green bond than coarse and uniform grained sands. Clay, especially colloidal material, is a good bonding agent for both green and dry molds. Organic binders such as molasses, glutrin, flour, etc., are good binders but burn out readily. Any such bonding agent must be well distributed over the surface of the sand grains in order to be effective; this can be accomplished only by thorough rubbing or mulling. Figure 66 illustrates a popular type of muller for foundry use.

Green bond may be measured by several methods:

1. *Transverse Strength.* A specimen of sand is rammed up into a 1 by 1 or 1 by 2-in. bar and then slowly pushed over the edge of a table. The average length or weight of the pieces that break off are taken as a measure of the bond.

2. *Tensile Strength.* A specimen of sand is rammed up in a special two-part cylinder, divided at right angles to its axis and clamped together; the clamp is released and the force required to pull the cylinder apart is measured in ounces per square inch.

3. *Compressive Strength.* A cylindrical specimen of sand is rammed up and broken in compression; results are recorded in pounds per square inch.

4. *Shear.* A cylindrical specimen is sheared along one or two planes; results are in pounds per square inch.

The transverse strength test is the least sensitive and hence the least accurate. Tensile and compression tests on similar sands are almost proportional; that is, the higher the tensile, the higher is the compressive strength. This relation does not hold for sands differing widely in permeability. Very open sands are usually weaker in compression than tight sands of the same tensile strength.

Dry bond is the strength which a sand or mold has after it has been dried or baked to remove moisture and harden the clay or other bonding material. Cohesion under such conditions is due solely to the close contact of the particles and this can be obtained only through colloidal bonding material. Hence, more or less sticky sands or organic binders must be used for dry sand molding. Dry bond varies with the mois-

ture content of a sand when rammed, increasing as moisture is increased through the practical working range; see Chart I. It is measured by ramming up a cylinder of sand while tempered, drying it and then breaking it under compression. Dry tensile strength can be measured by making a briquette like that used in testing concrete and then pulling it in a tensile testing machine. Both tensile and compressive strengths are measured in pounds per square inch.

Topical Questions

1. Discuss the relation between the fusion point and sintering tests.
2. Is dry bond strength desirable in green sand molding? Why?
3. A sample of silica sand bonded with bentonite has green tensile strength of 6 oz. per square inch and green compressive strength of 4 lb. per square inch. A sample of natural molding sand has green tensile strength of 5 oz. and green compressive strength of 5 lb. per square inch. In your opinion, which has the greater bond strength? Explain your answer.

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4. NEVIN, C. M., "Life of Molding Sands," *Transactions of American Foundrymen's Association*, Vol. XXXIII, p. 763.
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CHAPTER LV

MOLDING PROPERTIES—PERMEABILITY AND TEMPER

Permeability.—Permeability, also called openness and venting quality, refers to the rate at which gases can pass through the sand. Sand must be open enough to allow mold gases to pass through readily, otherwise blows, misruns, and even dirty castings result.

In general, the finer the grain and the less uniform its size, the less open or permeable will be the molds made from it. On the other hand, fine grain produces smoother mold surfaces and smoother castings. Large castings and heavy sections require open molds, so if smooth surfaces are required, it is necessary to use a fine sand facing backed up with open sand, or else surface the mold with a graphite or silica wash. It is to be remembered, however, that smooth mold surfaces alone cannot insure smooth castings; kind of metal and its pouring temperature are important factors.

Mold gases are from several sources. They consist of the air in the mold ahead of the molten metal; gas given off by the metal in cooling to freezing point and in freezing; water vapor from the moisture in the sand; and gases formed by the burning organic material in the cores and molding sand. The air in the mold and the gas given off by the metal must pass through the skin of the mold, through the sand, and out, or through vents made for the purpose. These gases are usually of small quantity. Molten metal of good quality gives off very little gas in freezing, usually less than its own volume. Wild metal may give off as much as 1 cu. ft. of gas per hundred pounds of metal. On the other hand, 1 oz. of moisture when evaporated produces about 1.7 cu. ft. of steam, so the heat from the molten metal for a 100 lb. casting may produce 10 to 20 cu. ft. of gas from the moisture and

organic matter in the cores and mold. If the cores and mold have the proper permeability, this gas need not enter the mold cavity but can pass off through the outer sections. It is to be noted that open flasks, perforated bottom boards, and artificial vents, as well as open sand and cores promote the escape of gases.

Permeability is determined by clay content, moisture, and degree of ramming, as well as grain fineness. Sticky clay in low percentages tends to form tiny chunks when tempered and these open up a sand. Much clay and silt close up a sand. Sands with insufficient moisture are tighter than properly tempered sand; permeability increases with increasing moisture to a maximum value and then decreases; see Chart I. Excessive ramming results in a tight mold as well as a hard one.

Permeability is measured by ramming up a standard test piece of sand in a cylinder, then passing air through it under a definite, measured pressure. The rate of flow is taken as a measure of the openness of the sand.

Temper.—Moisture content of heap and facing sand is a most important factor in the production of good castings; it is, also, most difficult to control because of its rapid change due to evaporation. Almost every other working property of molding sand is directly affected by temper. Plasticity, mobility, green and dry bond, and permeability all vary with moisture content, as illustrated in Chart I. In green sand molds, moisture is the chief source of mold gas. Excess water or wet spots in the mold cause the metal to boil, cutting into the surface and resulting in rough or dirty castings. It also hastens the cooling of the metal. It takes as much heat to vaporize the water in tempered sand as it does to heat the dry sand 300 or 400° F. This tends to make the metal less fluid and in some cases may cause misrun castings.

The moisture requirements of sands differ widely. Coarse grained sands bonded with a low percentage of sticky clay require but little water, $1\frac{1}{2}$ to 4 per cent. Fine sands and those containing much clay require from 5 to 8 per cent water and in exceptional cases 10 per cent. Organic binders also differ widely in this respect; some require much water to

develop their maximum bond while others work better when fairly dry. Sand for dry molding is usually worked with more moisture than that for green molds; mold gas is not such a serious problem.

As a general rule, molding sand should be worked at the lowest moisture content that will yield sufficient bond strength for the job at hand. Uniform distribution of moisture through the sand is all important.

Moisture is measured by weighing a sample of sand, drying and weighing it again. The loss in weight is calculated in per cent of the weight of the sample.

Topical Questions

1. Is it true that metal will not lie to a hard mold or hard core? Explain.
2. Blacking, graphite, or silica flour washes close the pores in the surface of the mold. Why is this less apt to cause blows than tight sand?
3. A cubic inch of tempered sand, when rammed in a mold, weighs about 1 oz. How many cubic inches of steam would be formed by 1 cu. in. of sand containing 6 per cent moisture? 8 per cent moisture?
4. Calculate the minimum number of cubic inches of steam formed on pouring an 8 in. stove lid in sand tempered to 6 per cent moisture if the sand is dried to a depth of $\frac{1}{16}$ in.

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CHAPTER LVI

SAND CONTROL

Sand control involves discovering by observation and experiment the properties of sand most satisfactory for the castings being made, equipment available, and methods being used; then maintaining these properties by frequent tests, proper additions of new sand and moisture, and thorough preparation for use.

The determination of proper characteristics is not an easy matter. There are so many variables involved, and so much depends on the molders' skill that definite conclusions can be drawn only after every factor has been taken into account, and when averages are taken over long periods. For instance, the low limit of permeability for a certain job can be determined only after the losses due to blows and misruns have been consistently high when the permeability has been below a certain figure. A short test may lead to wrong conclusions because cold metal, hard ramming, wet sand, or other causes might produce such a loss even though the sand is not too tight.

Permeability and green bond tests are most directly connected with molding properties and may be easily and rapidly made with comparatively simple equipment. Clay, fineness, and dry bond tests are valuable aids in control of sand and are not difficult to make, though more time is required. Usually these tests need not be made as frequently as permeability and bond tests.

Moisture control requires quick action in order to be effective. Samples taken from a continuous sand handling system can be weighed on small pendulum or spring scales of the direct reading type, dried at temperatures up to 400° F., and reweighed to give prompt results. Individual sand heaps are not so easily controlled and it becomes necessary to use

moisture tests to train the men handling the sand to better judge the proper temper.

Sand Additions.—New sands and bonding material should be selected on the basis of grain size, clay content, chemical analysis, price, etc., with reference to the work for which they are intended. Chemical analysis is, of course, given more attention in selecting steel sands than brass sands. For control purposes at least two and possibly three grades of sand should be stocked, permitting variation of grain size and clay content. If fine heap sand is used and coarser core sand gets into the heap in practice, the new sands will have to be finer than the heap in order to offset the coarse core sand. Large castings that burn out sand rapidly require new high clay sand additions.

Floor sweepings, burned sand, and even recovered core sand may be rebonded and used to advantage in some cases. Where sand requirements permit, the fines and organic material need not be removed; in other cases, the dry sand is worked to loosen the burned clay and then the fines are removed by air separation. The recovered sand is then bonded in a muller with new high clay sand, fire clay or bentonite.

Bentonite is a highly colloidal clay of volcanic origin. It is similar to low silica molding sands in chemical analysis, possibly a little higher in alkalies. It is very sticky and provides dry as well as green bond. It is valuable for producing very open high-bond sands. Though not highly refractory, it is finding use in steel as well as in iron and brass molding.

The sand slinger has given rise to new problems so far as sand requirements and control are concerned. This machine throws sand into the mold with considerable force. It packs sand tighter than it is usually rammed by other methods so more open sands are required. Good mobility or flowing quality is also required. Slinger sands are usually open, of rather low clay content and hard grain. They are worked dryer than the usual heap sand.

C. A. Hansen, General Electric Company, estimates that: "More castings are rejected through faulty use of essentially

suitable sands than are unavoidably lost through the use of essentially unsuitable sands."

Topical Questions

1. A foundry loss record shows a marked increase in blows, yet the daily permeability test on the sands shows no change. Mention possible causes.
2. Blows and misruns are frequently classified together on the casting loss sheet. Why?
3. Tests show that a certain job requires higher bond but the sand must not be closed up any. What type of bond addition should be made?
4. A floor is operating at low loss ramming up molds by hand. A sand slinger is installed. Recommend changes in the sand.
5. Outline a method for controlling temper in a foundry of 30 individual molding floors.

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CHAPTER LVII

BRASS FOUNDRY SANDS

Sources and Description.—Most of the molding sand for brass and other non-ferrous alloys used in American foundries is produced in the Albany district of eastern New York, northern and central Ohio, and northern Kentucky. The first mentioned district is the most widely known. Small quantities of very fine sand for statuary, ornamental, and small work are also obtained from Windsor Locks, Conn., and from France.

In general, these sands are not highly refractory and the clay is not very sticky. The following data are representative of the most popular of them:

Chemical Analysis:

Silica.....	75 to	80 per cent
Alumina.....	8 to	10 per cent
Iron oxide.....	3 to	6 per cent
Lime.....	1 to	2 per cent
Magnesia.....	0.5 to	1 per cent
Alkalies.....	2 to	5 per cent
Loss on ignition.....	2 to	6 per cent
Grain fineness.....	100 to	275
Clay	5 to	15 per cent
Dye adsorption.....	300 to	500

Molding Properties and Manipulation.—Pouring temperatures in a brass foundry range from 1800 to 2400° F., hence, sands need not be highly refractory. Small and medium brass castings burn out sand very slowly, hence, heavy clay sands are not required. Smooth surfaces are usually desirable so fairly tight sands of fine-grain size are used. They are of a soft, smooth texture, free of pebbles and clay chunks. While molding properties of satisfactory sand vary widely among brass foundries, due to different methods of gating, types of patterns and alloys, methods of making molds, etc.,

the following are the general properties of brass heap sand for light, medium, and heavy castings:

	Light	Medium	Heavy
Fineness.....	200 to 225	150 to 200	100 to 150
Clay.....	6 to 15 per cent	7 to 10 per cent	7 to 10 per cent
Permeability.....	8 to 12	10 to 17	17 to 25
Green bond, tensile.....	4.0 to 5.0 oz.	4.3 to 5.3 oz.	4.5 to 6.0 oz.
Compression.....	3.0 to 4.5 lb.	3.0 to 5.0 lb.	3.5 to 6.0 lb.

Organic bond, such as flour and dextrin, is seldom if ever used in brass molding sand, though flour is frequently dusted on mold faces or a spray of molasses water is applied to improve surfaces. Additions of new sand are frequently made directly to the heaps and cut in by hand; it is better practice to mix new sand with heap sand or screened floor sweepings in a muller, tempering it at the same time, and then cut it into the heap. Continuous feeding of new sand is desirable where continuous sand-conditioning machinery is operated.

With modern methods of machine molding there is a tendency to work heap sand too little. Rubbing or mulling action is necessary to keep the clay properly distributed, and this can be accomplished only by thorough cutting, tramping sand, or by actually mulling it. Ideal conditioning is obtained by mulling the tempered sand a few minutes and then passing it through an aerating or beating device. Low-bond strength is sometimes found in heap sand containing plenty of good clay and is usually due to improper or insufficient cutting.

Burned cores and core sand should be kept from brass sand as far as possible. It is usually coarser than the heap sand and the grain is free of clay. Considerable work is required to bond it properly.

Topical Questions

1. A large phosphor bronze casting is poured at 2400° F. Outline the sand requirements.
2. A small brass casting requires a very smooth surface but is prone to blow. Suggest ways to meet these conditions.

3. Sand used in making a certain valve-body core has a grain fineness of 60. The heap sand is 140. How will the burned core sand affect the permeability of the heap? The green bond?

4. A sand heap is low in green bond strength. Fineness and clay tests are up to standard. What is the trouble?

Reading Reference

GRUBE, A. A., "Reclaims Foundry Sands," *The Foundry*, Vol. LIV, No. 12, p. 461, June 15, 1926.

CHAPTER LVIII

IRON FOUNDRY SANDS

Sources and Description.—The sand requirements for small iron castings and stove plate are similar to those for brass. Pouring temperatures are, of course, higher, ranging from 2300° F. to 2600°F. for gray iron and 2600° F. to 2800° F. for malleable iron, so refractory requirements are greater. The same sands used for medium and large brass castings, however, are widely used for small, and in some special cases, for medium iron castings.

The Albany district of New York, and the states of New Jersey and Ohio supply a large proportion of the sand used for molding iron. In general, the New Jersey and central and southern Ohio sands are better adapted to large iron castings.

Satisfactory sand for large iron castings is fairly refractory, of high bond, and yet open. The following data are representative of such sands:

Chemical Analysis:

Silica.....	75 to 85 per cent
Alumina.....	8 to 10 per cent
Iron oxide.....	3 to 8 per cent
Lime.....	1 to 2 per cent
Magnesia.....	0.5 to 1 per cent
Alkalies.....	1 to 3 per cent
Loss on ignition.....	2 to 6 per cent

	Large castings	Medium castings
Grain fineness.....	25 to 80	80 to 125
Clay.....	10 to 15 per cent	10 to 15 per cent
Dye adsorption.....	800 up	500 to 1,000

The type of new sand employed varies widely according to molding practice.

Molding Properties and Manipulation.—The higher temperatures at which gray and malleable iron are poured give rise to conditions of mold gas, burning on, etc., that are not encountered to any great degree in brass. Sand is dried to a greater depth and consequently more mold gas is formed. The sand and the mold must then be open enough to carry it off. If smooth surfaces are desired, it becomes necessary to use a graphite wash on the surfaces or else face them with a fine sand. Although practice differs widely, the following data are representative of heap sand used in iron foundries:

	Large	Medium	Small casting or facing
Fineness.....	25 to 50	50 to 100	100 to 150
Clay.....	10 to 15 per cent	10 to 15 per cent	10 to 20 per cent
Permeability...	125 up	50 to 100	20 to 50
Green bond, tensile.....	6 to 10 oz.	4 to 9 oz.	4 to 9 oz.
Green bond, compression..	6 to 10 lb.	4 to 9 lb.	3 to 8 lb.

Water soluble binders such as molasses, dextrin, flour, etc., are used rather extensively in iron molding. In some cases, these binders are mixed in with the sand; in other cases, they are dissolved in water and sprayed on mold surfaces to form a sort of hard skin. In addition to the increase in strength, the gas developed tends to prevent burning on and produces smooth surfaces. This latter effect is also accomplished by the use of a few per cent of sea coal in the sand or facing. Sea coal, however, affords very little green bond and no dry bond. Excess amounts of such materials produce blows due to the formation of too much mold gas.

Iron breaks down the bond rather rapidly, so much work is needed to keep clay properly distributed on the grain. It is highly desirable to mull the sand, particularly the facing. It should then be aerated by means of a blade beater or a sand cutter. When sand cutters alone are used, repeated cuttings are desirable, seven or eight times are none too many where heavy work is being cast.

There is a marked tendency on the part of foundries making large, gray-iron castings to approach the sand practice of steel foundries. There is a tendency to use sands of higher silica content, and when low in bond, add clay or bentonite. Such mixtures must be mulled well. By such practice it is claimed that less burning on occurs, castings peel better, and sands and molds are better vented.

Many medium and large iron castings are made in dry molds. Rather sticky sands are used for this work and they are worked at slightly higher moisture contents than for green sand molding. The molds are either dried in ovens or the surface is dried out with torches or other heaters. Large castings are frequently made in loam molds. Loam molds are largely made without patterns. They are formed in pits or in rough brickwork forms in which the sand is tamped and troweled into shape. They may be backed up with gravel or cinder beds to provide free venting and are faced with high-bond sand rammed fairly hard.

Topical Questions

1. Mention difference in sand requirements for gray-iron and malleable castings of the same size.
2. Sea coal and water both form gas when they come in contact with molten metal. Why the difference in their effect on the casting?
3. What advantage is gained by working sand wet when making a mold that is to be dried? What disadvantage? Explain.
4. Outline the sand requirements for a very heavy gray-iron casting that must have a very smooth surface.

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2. HARRINGTON, WRIGHT, and HOSMER, "Practical and Technical Data Obtained from the Use of Clay Bond in Molding Sand Heaps," *Transactions of American Foundrymen's Association*, Vol. XXXIV, p. 307.
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CHAPTER LIX

STEEL FOUNDRY SANDS

Sources and Description.—Steel foundry sands are of two general classes: naturally bonded high-silica sands and bond-free silica sands to which clay and sometimes organic binders are added. Illinois and Missouri produce great quantities of high silica sand that contains but little clay. The steel sands of Ohio are but little lower in silica and carry a little more clay. Quantities of these low clay sands are washed almost entirely free of clay and marketed for sand-blasting and for core making as well as for steel molding. Much of it is ground in tube mills to produce silica flour. Pennsylvania and New Jersey produce most of the naturally bonded steel sands; those of the latter state are in general the higher in clay.

Data which are descriptive of the Illinois washed sand and the New Jersey naturally bonded sand are given below. The unwashed Illinois sand is a little lower in silica and a little higher in the other constituents; the steel sands of Ohio and Pennsylvania lie between them in composition and properties.

	Illinois (washed)	New Jersey
Chemical Analysis:		
Silica.....	98 + per cent	80 to 90 per cent
Alumina.....	0.1 to 1.5 per cent	3 to 12 per cent
Iron oxide.....	0 to 0.1 per cent	1 to 2 per cent
Magnesia.....	0. to 0.1 per cent	0.1 to 0.3 per cent
Lime.....	None	0.1 to 0.2 per cent
Alkalies.....	None	0.2 to 0.1 per cent
Loss on ignition.....	0 to 0.5 per cent	2 to 4 per cent
Grain fineness.....	25 to 50	50 to 100
Clay.....	0 to 1 per cent	4 to 10 per cent
Dye adsorption.....	15 to 50	300 to 2,000
Fusion point.....	3100 to 3125° F.	2950 to 3100° F.

Fire clays are used extensively for bonding steel sands when the natural bond is not sufficient. The following data are descriptive of such clays.

Chemical Analysis:

Silica.....	55 to 65 per cent
Alumina.....	20 to 30 per cent
Iron oxide.....	1 to 4 per cent
Magnesia.....	0 to 1 per cent
Lime.....	0 to 1 per cent
Alkalies.....	0 to 3 per cent
Loss on ignition.....	4 to 10 per cent
Dye adsorption.....	1,500 to 3,000
Fusion point.....	2950 to 3050° F

Silica flour is finely ground silica practically all of which passes a 200 mesh sieve. It is used for adding bond and for surfacing molds to prevent metal penetration.

Working Properties and Manipulation.—Steel is poured at temperatures ranging from 2750 to 2950° F. so is very destructive of the bonding material in sand. It is necessary, therefore, to use only the most refractory sands and these must be carefully rebonded or renewed before they can be used a second time. In some foundries, it is the practice to discard a large proportion of the burned sand, adding new sand to maintain proper strength. The high cost of good steel sand makes it advantageous to reduce the proportion of new sand as much as possible, so many foundries prepare facings of, say, 50 per cent old sand and 50 per cent new sand and clay or other binder, and back up the mold with old sand which has been tempered and mixed on the floor with a power sand cutter. The facing sand is usually mulled.

Facings for green sand molding are made from bond-free silica sands by adding from 1.5 to 4.0 per cent fire clay and about $\frac{1}{2}$ per cent of an organic binder, then tempering to 3 or 4 per cent moisture and mulling thoroughly. Silica flour is also added sometimes where permeability can be sacrificed in order to prevent metal penetration. A mixture of about one part molasses and fifty parts water is sometimes used for tempering. For dry-sand facing similar mixtures are used except that the percentage of clay is usually higher,

from 4 to 8 per cent, and the sand is worked at a little higher moisture content. Molds are rammed hard, yet with low-clay content they are usually open. The fire clay supplies a bond that is not destroyed in drying; it retains strength even at high temperatures during the pouring operation. The organic binders burn out readily allowing the mold to yield as the casting shrinks on freezing and cooling. The proportions of clay and organic binder are determined by the requirements of the mold as regards these points.

Facing sand for steel castings ranges in fineness from 25 to 75 according to the size of the castings. The clay content is usually between 2 and 6 per cent and so the sand is more open than gray-iron sands of the same fineness. The permeability ranges from 100 up. Tensile bond ranges from 6 to 10 oz. per square inch and compression from 4 to 8 lb. per square inch, yet the hard ramming employed results in a harder mold than is usually used for gray iron.

There is a tendency for burned clay, steel shot, etc., to accumulate in steel sand and this prevents the use of large proportions of old sand in making up facings. By proper screening, dry mulling, and air separation methods, most of this undesirable material can be removed. The remaining clean sand can be rebonded with a few per cent of clay and organic binder and thus produce excellent facing sand, at low cost, for new materials.

The tightness with which a mold is rammed is a very important factor. While the sands are not of exceptionally high green-tensile or compressive bond, they are usually rammed much harder than for gray iron.

Mold washes for steel are usually made of silica flour, molasses, and water. They are painted on the surface to improve surfaces and prevent burning on.

Dry sand molding is widely employed for steel castings of all sizes, especially if machining is required. Large steel castings are sometimes made in loam molds.

Topical Questions

1. What advantage is to be gained by bonding clean silica with fire clay as compared with naturally bonded steel sand? What disadvantage?

2. Explain why clays of low-heat resistance are unsuitable for use in steel sand, yet organic binders are used successfully.
3. Why must steel sands be more open than gray-iron sands for the same size of castings?

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CHAPTER LX

CORE SANDS

Properties of Cores and Core Sands.—The important properties of cores are (*a*) dry strength; (*b*) permeability; (*c*) smoothness of surface; (*d*) moisture resistance; (*e*) heat resistance; and (*f*) friability. Dry strength determines the fragility or ruggedness of the finished core and its ability to stand rough handling between the oven and the mold and to support loads in the mold. Permeability is necessary because cores are sometimes almost entirely surrounded with metal; and, while little if any water vapor is formed in dry cores, gas from burning core binders and other mold gases must be permitted to escape. Core surface is important because it is a major factor in forming smooth castings. When cores are allowed to remain in storage for long periods, at room temperature, or lie in damp molds for considerable time, they should not absorb moisture and become soft. Cores must resist the fusing action of molten metal, otherwise they “burn on” to the castings or allow the metal to bite into their surface. In either case, rough castings result. Though cores should be resistant to fusion, it is frequently required that they be friable after the casting has been poured; that is, they must be easily broken up and removed from the casting.

The green core sand mixture also has certain properties on which its workability depends. The most important of these are green bond, plasticity, stickiness, and rate of drying. Sands of high green bond are required for making cores of intricate design, and supporting and handling them without special equipment, such as dryers.

All the above properties are determined by the selection of sands and binders and the proportions and manner in which they are mixed.

Core Sands.—High-silica sands of low or no clay content are usually used as the base of core sand mixtures. They are highly resistant to heat, open, and of low green bond. The Ottawa sands are the cleanest and most refractory of these, but dune or lake sand from the shores of the Great Lakes, such as Michigan City sand, and shore sand from the Atlantic Coast are of a more desirable grain size and are more widely used. Low-clay bank sands of grain fineness 60 to 100 are also widely used. Molding sand, foundry floor sweepings, and silica flour are used to impart green bond and fine texture. Sands of high colloidal content supply good green bond but require much oil to bind them. Silica flour, though finely ground, has a very low dye-adsorption value, as it is not colloidal.

Core Binders.—Three general types of core binders are used: (a) oils; (b) water soluble binders, and (c) resins. Drying and semi-drying oils such as linseed, rapeseed, soy bean, and corn oil become hard under heat due to oxidation rather than the loss of moisture, so air must be supplied to oil-bound cores in baking. Non-drying oils such as kerosene, fuel oil, and paraffin oil are almost entirely evaporated in the baking process and so have no bonding value; they are used to dilute oil binders and to prevent sands from sticking to core boxes. Water soluble binders such as flour, dextrin, glutrin, etc., are much cheaper than oils and afford more green bond. They become hard upon losing moisture but readily absorb moisture and become soft after standing a time in a green mold. Resin binders such as rosin, pitch, etc., become soft upon heating, stick to the grains of sand, and become hard again upon cooling. Cores made with such binders are soft while hot and yield readily with the casting as the metal shrinks. All organic binders, such as the above, are broken down at temperatures under those of molten metal resulting in cores that are easily removed. Clay, Portland cement, and such mineral binders are good bonding materials, but become very hard or at least fail to break down when the castings are poured, so difficulty may be encountered in cleaning the castings.

Methods of Mixing.—Aside from hand, shovel, and riddle methods of mixing used in small foundries, two types of power mixers are in general use; they are the blade and muller types. Blade mixers usually require less power and are very effective for oil binders. Mullers are more effective in distributing floury and colloidal binders on the grains and developing green bond.

Topical Questions

1. In general which should be the more open, the core or the mold for a given casting? Why?
2. How select a core sand that will be economical in oil binder requirements?
3. Under what conditions would it be advantageous to dilute an oil binder with fuel oil or other non-drying oil? When would this be a disadvantage?
4. Mention core troubles that might be due to improper mixing of sands.
5. In what respects are molding and core sands similar? In what respects should they differ?

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2. HANSEN, C. A., "Some Properties of Core Oils," *Transactions of American Foundrymen's Association*, Vol. XXXIV, p. 577.
3. HARPER, J. F., and STEVENSON, W. J., "Methods of Testing Core Sand Mixtures," *Transactions of American Foundrymen's Association*, Vol. XXXIII, p. 817.
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CHAPTER LXI

CORE SANDS—CONTINUED

Blending of Core Sands.—Maximum values of green bond, dry strength, permeability, and texture (smoothness of surface) are not easily obtained in the same core sand mixture. Sands of high green bond are usually tight or require much binder. Open cores are frequently rough. It is necessary, therefore, to compromise on some of the properties in order to meet the requirements of the castings.

Chart II shows how core sand properties vary with different proportions of sharp and bonding sand. The sharp sand charted is a clean silica of low-colloid content (low dye-absorption value). Silica flour absorbs but little oil compared with colloidal bonding materials such as molding sand.

Greatest heat resisting properties are obtained by the use of high-silica sands such as Ottawa, lake sands, silica flour, etc. Green bond and fine texture are obtained by using fine grain or by adding silica flour, molding sand or foundry floor sweepings (also called "runway sand"). Open cores are made from coarse or uniform grained sands bonded with a colloidal material such as clay or organic binders.

Coarse sands and clean silica mixtures require less binder to produce the desired dry strength than do mixtures containing molding or runway sand. This is particularly true of oil binders and in a less degree of water soluble and gum binders. This difference in binder requirements is highly important because oil binders usually represent from a quarter to a half of the cost of a core-sand mixture.

Straight silica sands bonded with oil are less plastic than molding sand mixtures. They yield less under pressure; overramming is less apt to produce tight cores, and differences in temper affect the hardness and permeability of the cores to a less degree. The cores are a little more brittle while

green and so are subject to fracture or other damage just a little more than those made from a molding sand mixture of the same green bond. This is due to the absence of colloidal material and may be remedied somewhat by the use

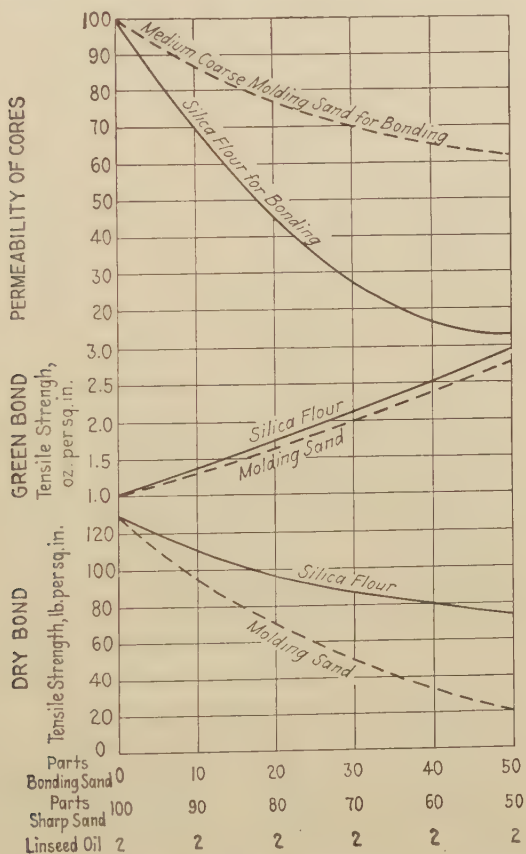


CHART II.—Permeability and green bond of core sand mixtures, and dry bond of cores made from mixtures of sharp sand and bonding sands: Silica flour and molding sand were used for bonding the sharp sand.

of water soluble binders where conditions will permit. Such cores are usually removed from castings more readily than those containing mineral colloids such as clay.

Certain advantages are gained, however, by the use of molding sands or small percentages of colloidal clay. Such

mixtures afford maximum permeability for a given bond (see Chart II). They are adapted to jobs which must be very open and yet cannot be made from sands of low bond. This is due to the fact that the needed green bond is obtained by coating the large grains of sharp sand with a quantity of very sticky clay which is small in comparison with the amount of non-colloidal but fine material which would be required to produce the same bond. The pores are thus left more open. Such clay, however, absorbs oil to a remarkable degree; hence, extra binder is required.

Cores which must yield readily with the shrinking of the cooling metal are usually made from rosin bound sand. Such cores are used for aluminum, also, in order that they may easily be knocked out. Rosin softens and is burned out at comparatively low temperatures.

Core Making and Baking.—Gray iron, aluminum, or wooden core boxes are usually used for shaping or “ramming up” cores. The tempered sand is pressed into the boxes by various methods; jolt or squeeze machines are used in some cases, in others the sand is blown in by specially designed core blowing machines, while in other cases the sand is tamped or jarred in by hand. Where exceedingly hard cores are desired, air rammers are sometimes used.

Cores of such shape and size that the bond alone cannot support them are wired or rodged to give them strength while green as well as after they have been dried. These rods or wires are placed well under the surfaces of the cores. They are sometimes coated with molasses or paste or even core oil so that the sand will stick to them. Cores are supported on metal plates until baked. These plates are sometimes of special designs to adapt them to support certain shapes. Intricate cores which must be made of very open low-bond sand are either rested in metal dryers, shaped to support the core at several points, or bedded in coarse sand for support.

Cores of such design that sand cannot be properly rammed into all corners and pockets are made in halves. Each half of the box is rammed up separately, the surfaces stroked off, then pressed firmly together. Thin plates, called “ram up” plates, are sometimes fitted on the edges of one of the half

boxes, to increase its depth slightly; after ramming the sand and striking it off, this plate is removed; this gives greater pressure of contact between the two halves so that better union is obtained.

When a fine tight sand must be used to get smooth surfaces and there is a tendency for the core to blow, artificial vents are made. These can usually be made by thrusting a pointed wire into the core after it has been rammed up and then withdrawing it. Where the section is small and the vent must be carefully located, the core is rammed up in halves, the vent wire laid in, the halves pressed together and rapped, then the wire is pulled out. When the vent must be other than a straight one, it is grooved in one or both halves and, to prevent stopping the vent, the box is rapped but lightly after closing. Strings of vent wax are sometimes laid in and allowed to remain until the baking process melts or evaporates the wax leaving a vent for gases.

Facing and backing sands are used in large cores as in molds to provide smooth or hard surfaces and yet permit escape of core and mold gases. The interior of large cores is sometimes filled with cinders, crushed coke, or weak bonded sand to provide vent for core gases and also to allow the core to yield during the solidification and contraction of the metal. The removal of the cores from the castings is facilitated by the use of a soft center or non-bonded material.

A paste of dextrin, glutrin or similar material and water is used to paste cores together. A mixture of dextrin and glue dissolved in water in a glue pot provides a paste that sets very quickly. A thick paste of graphite or silica flour and water with possibly a little molasses for binder is used for repairing cores which are slightly damaged.

Cores are baked at temperatures ranging from 225 to 450° F. Long bakes at low temperatures produce uniformly baked cores but for heavy production higher temperatures are required. Rapid baking at high temperatures tends on large cores to form hard skins with green interiors. Under-baked cores tend to bake in the casting when the metal is poured and result in difficult cleaning.

Oil bound cores require a supply of fresh air in order to bake properly, so must be spaced on the plates to admit air to all surfaces. Smoky, poorly ventilated ovens usually produce poor cores.

Green sand cores are sometimes used where conditions will permit. They are rammed up on a mandrel or other support and placed in the mold while green or after the surface has been dried slightly.

Topical Questions

1. A core sand mixture for brass cores is composed of 80 parts Michigan City sand, 20 parts runway sand, and 2 parts linseed oil. Trouble is experienced knocking the cores out of the castings. Suggest a change to remedy this trouble and mention the effect of this change on other properties of the core.

2. Silica flour costs about three times as much as molding sand. How can its use in core sand be justified?

3. Suggest sand and binder mixture for a hard smooth-surfaced core that must yield with the metal and come out of the casting easily. Suggest a method of making such a core.

4. What tests should be made to aid in selecting core sands? In selecting an oil binder?

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PART XI
ELEMENTARY PROBLEMS IN ELECTRIC
STEEL FOUNDRY PRODUCTION

The four chapters of this Part were prepared by
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CHAPTER LXII

THE PROPER FIELD OF THE ELECTRIC FURNACE IN STEEL CASTING MANUFACTURE

Before the chief problems involved in making electric steel castings can be intelligently considered, something should be known about the kind of castings that can best be made from electric steel. Knowledge along this line is becoming more important every year because of the growing volume of electric steel castings made in the United States. Starting in 1908 with a production in this country totaling only 55 tons, the electric branch of the steel casting industry has grown rapidly until in 1926 it produced approximately 360,000 net tons, amounting to more than 24 per cent of all the steel castings made in the United States. This output came from a total of about 180 foundries, which make electric steel for castings, out of a total of approximately 350 steel foundries of all kinds in this country.

There are important reasons for the rapid growth of the electric branch of the industry. It will not require much space to explain these, and it is important for any one who expects to work in steel foundries and hopes later on to hold higher positions in them, to know just what the reasons are for using the electric furnace for certain kinds of steel castings.

First of all, an electric steel foundry is especially suited to the production of small and medium-sized castings. This is because the melting operation in the electric furnace can be carried on practically without any limitation as to the temperature in the furnace. If the electric current, which is always under the control of the melter, is applied long enough at suitable voltages, the metal (which has a shallow depth in what is called the bath or basin of liquid steel) may be brought quickly to a temperature much higher than that which may be maintained in an open-hearth furnace, without serious injury to its brick-lined roof.

The electric furnace roof, while made of the same material as that of an open-hearth furnace, is of small size to correspond with the size and round shape of the furnace itself. It is the regular practice to have a spare roof ready at all times to put on an electric steel furnace whenever the old roof becomes damaged too much from the heat. Such a change of roofs is not possible with an open-hearth furnace which, for eco-



FIG. 67.—Electric steel furnace.

nomical operation in the foundry, is ordinarily of about 25-ton capacity and approximately 45 ft. long by 15 ft. wide. The roofs on these furnaces cannot be bodily lifted on and off. That means that an open-hearth furnace roof when partially damaged requires the shutdown of the furnace for several days before the brick work of the roof structure may be rebuilt.

The converter is just as satisfactory as the electric furnace, from the standpoint of making metal hot enough for thin castings. But the cost of running a converter, including the

expense of the pig iron for the charge, as compared with the cost of buying steel scrap for making electric steel, has, during the last few years, resulted in the installation of many electric furnaces to take the place of converters. One reason for the high cost of running a converter is what is termed the oxidation or melting loss. When making converter steel, not more than 85 per cent of the cold metal making up the charge comes out of the converter for pouring into the molds. When producing electric steel, about 95 per cent of the metal composing the charge is poured into molds.

The construction, during the last ten years, of large modern electric power plants, by companies selling electricity, has brought about a lowering of the rates charged for electric current, so that this provides another reason for the present large number of electric steel furnaces in use for making castings.

It is best for foundry purposes to use an electric steel furnace of from 1 to 5-ton capacity. That means the weight of the cold metal or charge put into the furnace to make a heat. Most electric steel furnaces in the foundry are of 3-ton capacity. Experience shows that this size of electric furnace is economical and convenient when making small castings requiring many pouring operations for the molds to be filled. It was mentioned previously that the electric steel foundry is especially suited to the production of small and medium-sized castings.

Open-hearth steel from furnaces such as are commonly used in the steel foundry is made at a cost considerably lower than the expense of making electric steel when in both cases metal that is only fairly hot or fluid is needed. This fact gives the open-hearth furnace a great advantage over the electric furnace when making large steel castings. For the production of that kind of work, the electric furnace is not economical.

We may see from what has been said that it is very important to select the kind of furnace for the class of work to be made.

Topical Questions

1. Compare steel and gray-iron castings as to composition and qualities.
2. State four causes of the growth of the electric steel foundry. Which of these or other causes may continue to encourage its development in relation to other types of steel foundries?
3. For what types of castings is the electric steel furnace not suited? Why? What furnace is suited to the making of these castings not usually made in electric furnaces? Why?
4. What is the difference between the holding and the 24-hour capacity of electric steel furnaces? (The A B C of Iron and Steel.) What are several advantages and one limitation of the electric steel furnace because of the difference between its holding and its 24-hour capacity?
5. What is melting loss? Which is it, relatively high or relatively low, in electric steel furnaces? Explain.

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CHAPTER LXIII

PROBLEMS RELATED TO HIGH TEMPERATURE OF METAL AND TO SAND

During the last 15 years there has been a great deal of good work done in designing small parts made of cast steel for many kinds of machines. Some of this equipment has been of very modern introduction. Formerly, for certain machines many expensive parts made of forged steel were



FIG. 68.—Modern electric steel foundry.

used. In other cases, malleable and gray-iron castings were employed. The fortunate combination of comparatively low cost and great strength existing in steel castings has caused many who previously used expensive forgings and the weaker iron castings to employ steel castings when building their machines. This has had much to do with the large tonnage of electric steel castings now being made.

It may now be understood that the problems of the electric steel foundry are chiefly related to the manufacture of small and medium-sized castings. One whose work does not make him well informed concerning such matters, is not apt to realize the difference in the appearance of a small steel casting and that of a large steel casting, when each is made in a foundry using satisfactory methods for its own kind of work.

Probably the average weight of a casting made in the ordinary electric steel foundry runs between 15 and 50 lb. Large steel castings often weight many tons each, and some are of huge size. The larger castings, as a rule, are used for purposes where a very nice surface appearance is unnecessary. On the other hand, the smaller steel castings, as made in electric foundries, generally are used where surface appearance is very important, as for example, in the construction of motor trucks, machine tools like lathes, drill presses, etc., and any number of pieces of equipment which do not sell well unless they look well, no matter how strong they are.

Difficulties Related to High Temperature of Metal.—For these reasons, the metal made in electric steel foundries, intended usually for many thin castings, must be very hot, so that it will be sufficiently fluid to fill the mold. The equipment and methods for cleaning the castings, therefore, must be different from the equipment and methods suitable for open-hearth foundries making large castings. All of this brings about the need, in electric steel foundries, for much more care in certain details of manufacture than is used in foundries making large work. The high temperature of the metal required for small castings intensifies a problem which is found in all steel foundries.

A problem, in the electric as in any other kind of steel foundry, which frequently requires great experience and skill, for solution, is the high degree of shrinkage of the metal when it becomes solidified after pouring. This shrinkage, roughly speaking, in liquid steel is approximately twice as great as in iron. Usually a steel casting of ordinary design will shrink $\frac{1}{4}$ in. per foot of length.

Naturally, the hotter the steel the greater the shrinkage. This means that the metal in an electric steel foundry pro-

ducing castings of small sections has a greater degree of shrinkage, other things being equal, than steel tapped from a furnace just hot enough to run a large casting having thick members. Thus, we see that the shrinkage problem is peculiarly associated with the manufacture of electric steel castings. Provision for shrinkage is of great importance in the successful production of those castings which, because of complicated shapes, do not freely permit all members to contract naturally while solidifying.

The Problem of Sands.—From what has been said about the high temperature at which steel is poured and the small size of many of the castings, it is evident that sand must be mixed and handled with care. Consider a mold for a small casting which the molder has closed without taking enough pains to remove sand that became loosened when the pattern was drawn or when the gate stick was lifted out.

When a small steel casting is poured in such a mold, this loose sand or dirt will frequently lodge in the upper part of the casting, forming what looks like a slag spot. This defect may be of comparatively small size. On a large steel casting no one would pay any attention to it unless the casting were intended for some very special purpose. A defect of this kind on a bed plate for a large hydraulic press would be insignificant, but on an exposed bracket for a motor truck it would be very objectionable.

While the cleaning methods in electric steel foundries are chosen with special regard for making nicely polished surfaces free from adhering sand, annealing scale, etc., the producing end of the shop must employ such methods as will make the least possible number of small defects, so that many of these will not have to be repaired in the cleaning or finishing department.

This necessitates a higher degree of carefulness in the preparation of the sand mixtures, in the supervision of molding and coremaking, in methods insuring molds being thoroughly clean when they are poured, and in numerous other shop details. All these are of importance in the manufacture of castings as perfect in appearance and as strong as possible so that every one will look well and will not break under severe service conditions.

It might be thought by some who are familiar with iron foundry work that there should be no great difficulty in making thin steel castings of very smooth appearance, such as are readily made in an iron foundry. There is a great difference in the temperature of steel required to pour a mold, say $3\frac{1}{8}$ in. thick and 2 in. long, as compared with the temperature of iron for making a casting of the same shape and size. This is due to the relatively small proportion of carbon in steel as compared with iron. Other things being equal, the higher the carbon, the greater the fluidity.

This means that when the temperatures are the same, steel, which contains a very low percentage of carbon, is very difficult to run a mold that would be filled readily by liquid iron, if the iron had the same temperature as the steel. To get the required fluidity of the more sluggish steel, very hot metal is necessary. This, of course, causes difficulties with respect to the material forming the sand mold, which are not present in the iron foundry. Steel suitable for making thin castings is generally poured at a temperature around 3000° F., which is considerably higher than the temperature of iron sufficiently fluid for foundry purposes.

This hot steel necessitates in the mold a high degree of what is called refractoriness, or ability to withstand heat. The materials entering into the composition of the sand mold in the steel foundry must, therefore, be selected with great regard for their tendency not to fuse or become partially or wholly molten at a fairly high temperature.

Silica sand is the most common refractory material in the earth. Steel molding sand must have a high percentage of silica, because otherwise the lime and other ingredients in the ordinary sands, such as are found everywhere, cause the material to become melted at a temperature too low for the pouring of steel castings even of average size.

The silica sand that is quarried and sold for steel molding purposes usually contains as much as 97 per cent silica. Sand of this kind does not have what we call bond to any noticeable extent. When water is mixed with it, it does not become sticky or plastic. When rammed it will not hold its shape. It must have a binder added to it. There are many

bonding materials of such nature as to give the desired firmness to the rammed sand, but which are of such a low melting point as to be utterly useless when mixed with silica sand for steel molding purposes.

It is, probably, now understood why the ingredients of steel facing sands must be chosen with great regard for refractory properties. Furthermore, they must be thoroughly mixed because in nearly every case the bonding material is



FIG. 69.—A molding floor in a modern electric steel foundry.

less refractory than the silica sand, which is the chief ingredient. It is necessary that this bonding material be well distributed; otherwise, in order to get the required workability in the facing sand, it would require the addition of too much of the binder having lower refractoriness. This calls for expensive equipment for sand mixing in the steel foundry, and particularly in the foundry where small steel castings are made; because, the smaller the casting, the more fluid the metal must be and the higher the temperature of the steel, necessitating the maximum resistance to fusion of the sand mold.

From the explanation it will, undoubtedly, be clear that from the standpoint primarily of the metal, involving necessarily the nature of the molds, an electric steel foundry of average type presents problems that, in certain important respects, are greater than problems of similar nature in other kinds of foundries.

Topical Questions

1. What figures other than those given in the table for the linear expansion of metals must one have in order to make a calculation showing how much greater the shrinkage of steel castings is than that of gray iron?
2. Find the data you referred to in answering the previous question and calculate the shrinkages of steel and of iron castings 2 ft. in length.
3. Refer to Chap. VI, in Part I on "Expansion, Contraction, and Shrinkage" and indicate all the ways mentioned in this chapter for preventing shrinkage and designate those that might be applicable in the steel foundry.
4. What two methods of increasing fluidity in some classes of gray-iron castings cannot be used in the electric steel foundry? Explain.
5. What kind of a change takes place when silica sand and lime are heated together at very high temperatures?

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CHAPTER LXIV

MELTING, POURING, AND GENERAL EQUIPMENT

The electric furnace in American steel foundries, as previously indicated, is frequently of 3-ton capacity. Generally it has 3 electrodes piercing the roof, and the current plays between the ends of the electrodes, and between the electrodes and the bath or liquid basin of metal. In nearly all electric steel foundries in this country, the lining of the

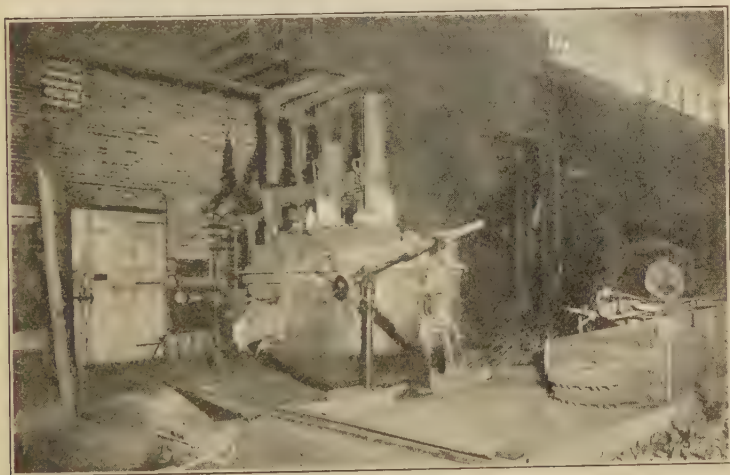


FIG. 70.—Electrodes in electric furnace.

furnace is of acid material consisting of silica sand or ganister, which is a rock containing a high percentage of silica.

The raw materials for a heat are usually charged cold, and the time required for making a heat from power on to power off frequently amounts to about an hour and a half.

The acid lining permits no change in the percentages of phosphorus and sulphur, but the amounts of carbon, manganese, and silicon are greatly lowered by the melting operation. Such additional percentages of carbon, manganese, and silicon, and

such amounts of any other elements for making alloy steels as are desired are added at proper times for the distribution of these ingredients.

The metallurgical changes that take place in the electric furnace are too complicated to justify an attempt to explain them here. It is proper, however, to point out that the very nature of electric furnace operation permits the production of steel having the lowest possible percentage of harmful oxides in the metal. This is due to the fact that oxygen is not required for combustion of the fuel as is the case in other



Fig. 71.—Shank pot being filled from teapot spout ladle.

types of steel furnaces except the old, almost obsolete, crucible furnace.

The pouring of steel is a very important feature of the satisfactory manufacture of castings. In the electric steel foundry, much of the work is poured from shank pots holding metal taken from bull ladles which empty the steel either over the lip or by means of a teapot spout. In rare cases, electric steel foundries use large ladles having a bottom-pour device such as is customarily found in open-hearth steel plants.

The shank pots used in the steel foundry are handled by two men, and much care is given to the satisfactory condition of the lining of these pots to prevent their becoming sufficiently damaged by high temperature to slough off in particles of liquid slag floating on the surface of the steel. When this

condition exists in an exaggerated degree, the liquid slag is apt to enter the mold proper, no matter how carefully the workman uses his skimming tool while the pot is being emptied.

The use of the teapot spout in the bull ladle is intended to reduce the amount of liquid slag emptied from it into the shank pots. The bottom-pour ladle serves the same and other purposes.

The linings of the large ladles last much longer than those of the shank pots. Their condition, however, is constantly examined with care from the standpoint of serious injury sustained from the hot steel, and from the standpoint of suitably high temperature before the metal is tapped from the furnace. A cold bull ladle or shank ladle is ruinous to the steel poured into it, no matter how hot the metal was when tapped from the furnace. By its very nature, the metal is extremely sensitive to temperature changes, and chills or freezes very quickly.

Only by experience can good judgment in pouring certain special types of molds be acquired. Some castings are of such nature as to call for great skill on the part of the pourer. The speed with which he may fill the mold is regulated largely by the nature of the gate and runner. These may be of such unsuitable design as to cause trouble despite the best skill of the man who pours the metal.

It may be understood from what has been said that the pouring of steel for making small castings is a rather complicated procedure involving several kinds of ladles for one heat, each kind having its own problems with reference to lining, temperature, and manipulation. All of these factors are important in the filling of the mold cavity.

Pattern Equipment.—It is unnecessary to explain at length the peculiarities of pattern equipment in an electric steel foundry. The questions that must be settled every day relate to the proper allowances for shrinkage in the different members, and perhaps to the tendency of the castings to crack while red hot during the solidification stage, if the conditions of the molds, including the designs and locations of gates and risers, are not such as to accommodate themselves to the castings.

In the electric steel foundry, many castings are produced from mounted patterns. These are very much more satisfactory than those not mounted when smooth castings made close to drawing dimensions are particularly desired. Follow boards are commonly seen in electric steel foundries, being adapted for the various flask sizes locally used as well as for the molding machines in the shop.

Some electric steel foundries systematically provide, for the molders, auxiliary pattern equipment consisting of special sticks and blocks of suitable proportions for risers, so that these men will not have to depend on their own judgment as to the proportions of heads or risers for the castings. Fillets of liberal sizes are advisable to use on all steel castings, whatever their sections may be. An up-to-date steel foundry gives much attention to the fillets on the patterns received from its customers and generally has no difficulty in getting permission to apply larger fillets when these are needed to make a good job. Sharp corners and the comparative absence of fillets are apt to cause cracks, especially when the design of the casting is complicated. These should be avoided whenever possible. A good molder in a jobbing shop will call the attention of the foreman to a very small fillet in a dangerous place on a pattern which has just come into the shop.

Molding and Core Equipment.—In an electric steel foundry much of the molding machine equipment consists of squeezers and jarring machines, the latter being intended for the larger molds. These are described in Part XII, "Molding Machines."

The preparation of the facing sand in an electric steel foundry, as will be appreciated from what has been said, is a more important detail of operation than it is in most foundries of other kinds. The customary type of steel foundry sand mixer consists of a pan with two revolving rollers. Sometimes the pan is stationary and sometimes it revolves, depending on the design of the mixer. Plows are placed at suitable distances to continually throw the mixture in front of the rollers. In up-to-date electric steel foundries, the plows are given constant attention so as to insure their doing what is expected of them. They are a very important although small detail of this kind of equipment. Well regulated steel

foundries require the sand mill men to mix the ingredients in the pan for certain periods of time, and to be very careful about the addition of no more than enough moisture to make the facing workable, without being so wet as to cause the generation of too much steam and other gases when the liquid metal strikes the damp mold.

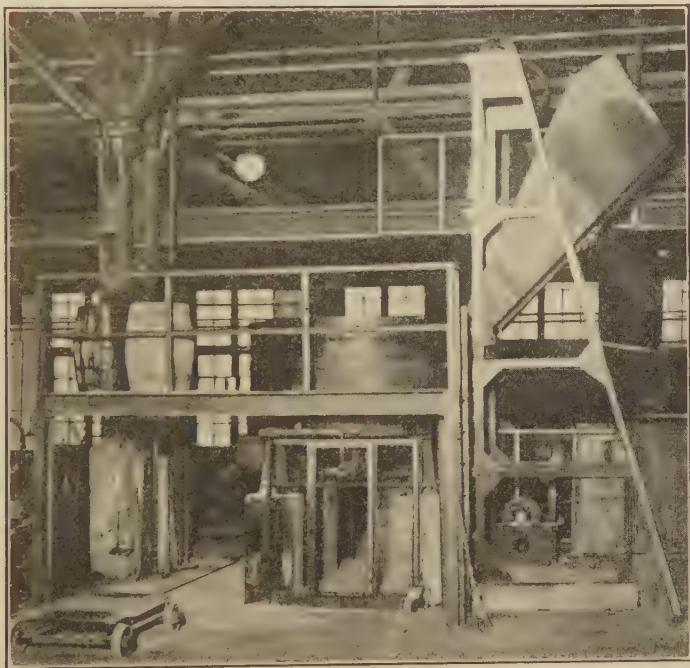


FIG. 72.—Sand mixer in use in the steel foundry of the General Electric Company, West Lynn, Massachusetts. (Courtesy of National Engineering Company.)

Core room equipment in an electric steel foundry does not differ greatly from such equipment in other foundries, except, perhaps, for the greater number of mechanical mixers in steel foundry core rooms as compared with others. The chances of trouble from improperly selected or poorly mixed sand, either for a mold or for a core in the steel foundry, are greater than in other foundries. And the smaller the casting the greater the chances for difficulties which exist. For these reasons, sand preparation in the core as well as in the molding

departments of an electric steel foundry receives constant careful supervision.

Topical Questions

1. Why does the silica sand or ganister used in lining the furnace produce no change in the percentage of phosphorus? In what kind of furnaces is the percentage of phosphorus in iron reduced and how? (See chapter on phosphorus.)
2. Why would you expect steel to chill or freeze very rapidly?
3. Why does the use of fillets decrease the danger of castings cracking?
4. Mention three elements referred to in this lesson which can produce acid reactions under certain circumstances. What are two foundry materials which produce basic reactions?
5. Explain two difficulties that might result from shank pots not being properly heated before use.
6. What economies in production mentioned in this lesson are peculiar to electric furnaces?

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2. "Keeping Shrinkage Cavities Out of Castings," Electric Steel Founders' Research Group, Chicago, Ill., *Research Group News*, Vol. 1, No. 4, January, 1925.
3. HALL, JOHN HOWE, "The Steel Foundry," 2d Ed., 1922, "Molding, Pouring and Digging Out," Chap. VIII.

CHAPTER LXV

EQUIPMENT—CONTINUED

Heat Treating Equipment.—It is generally known that steel castings should be annealed, in order to develop the greatest resistance to service conditions by the refinement of the granular structure of the metal, as well as to relieve certain internal strains sometimes caused during cooling. These strains might cause the failure of a casting if it is not heat treated.

“Heat treatment” is a term frequently used in the past to mean a series of heating and cooling operations, such as are not ordinarily required for steel castings of the regular grade of steel used for ordinary purposes. The term heat treatment now, however, is properly used for any method of heating and cooling a casting whether it is repeated, or not, in the same or slightly different form.

The usual term employed for heat treatment in the steel foundry is “annealing.” This term may be used to define a heating operation followed either by oven cooling or by air cooling. When steel castings are cooled in the air after removal from the annealing oven, the operation is called normalizing. There is no single term now proper to use which means heating followed always by furnace cooling. Thus, it is seen that the word “annealing” has a general significance and is applied in air or furnace cooling according to the nature of the castings and the duty they are expected to perform.

It is impossible, in a brief summary of this kind, to explain scientifically the changes that take place in a steel casting during heat treatment operations. It is enough to say here that the equipment in an electric steel foundry, for doing this work, is expensive and elaborate because the annealing of the product and the complicated heat treatment of certain castings, must be performed according to the most carefully

regulated procedures based on scientific knowledge of the remarkable changes in the metal, brought about by heat treatments. Pyrometers of indicating and recording types, which are instruments for registering high temperatures, are regularly used. Definite temperatures must be maintained for stated periods. The product of the steel foundry is remarkably responsive to this detail of operation incidental to but separate from the making of the metal itself.



FIG. 73.—A cleaning room in a modern electric steel foundry.

The cleaning room equipment in an electric steel foundry is one of its most distinguishing features. This is due to the importance of appearance, as mentioned previously. Swing grinders, stand grinders, pneumatic chipping hammers, tumbling barrels, blasting machines for sand or metal abrasives, oxy-acetylene torches for cutting off risers and gates and for welding, and electric welding machines are found in the cleaning room of an electric steel foundry. In addition, there may be machines for applying test pressures to castings for pipe lines and containers of various kinds of liquids and gases. It is necessary to thoroughly systematize the cleaning

operations, which require a regular flow of work from one machine and gang of men to another, in order that all of this work may be done without ruinous expense. Each operation in cleaning a casting must be carefully supervised to prohibit, so far as possible, rerouting castings for a second application of the same cleaning procedure.

Throughout all the cleaning operations there is constant watch for defects, that the cost of cleaning an unsuitable casting may be prevented. The inspection staff is busily



FIG. 74.—A laboratory in a modern electric steel foundry.

occupied, without a break, in a shop of the kind where many thousand castings of a very large variety of designs are manufactured each month. Inspectors must constantly furnish information which can be acted upon in other departments, such as the molding floor and core room, to prevent duplicating unsatisfactory work causing excessive cleaning expense or the total loss of castings.

Laboratory Equipment.—In the modern electric steel foundry, there must exist, on the ground, equipment for making chemical analyses of the product and certain important raw materials of which it is composed. There should

be, also, at the plant, or conveniently near it, apparatus for making physical tests of various kinds required by certain specifications, as well as apparatus for carrying on researches to continually improve the steel and to find out how it will behave under various forms of service. The microscope is of occasional use for studying the physical structure and determining the extent and nature of impurities.

Laboratory facilities are essential to much greater extent for any kind of steel plant than they are for iron and other foundries. One reason for this is the remarkable way in which one may get a great variety of physical properties, depending on the chemical composition and on the heat treatment. No other metal has such a large number of possibilities for giving different values indicating toughness, hardness, etc. Steel castings are purchased with much greater regard for the resistance of the material to strains and shocks than is the case with other kinds of castings. This necessitates the utmost care in the daily production of the metal and constant watchfulness to see that every detail of the molding operation is suitable.

Occupations.—Many who are not familiar with operations in an electric steel foundry are surprised when they learn of the large number of skilled and semi-skilled trades represented. In every such foundry, one may find men doing work indicated by the following list:

1. Blacksmiths
2. Blasters
3. Carpenters
4. Casting chasers (for order department)
5. Casting checkers (for samples, gaging, etc.)
6. Chippers
7. Core makers
8. Crane runners
9. Cutting torch men
10. Electricians
11. Grinders (swing and stand)
12. Laboratory assistants
13. Ladle liners and dryers

14. Machinists
15. Melters and furnace helpers
16. Millwrights
17. Molders
18. Oven tenders (heat treating, mold, and core)
19. Pattern makers (wood and metal)
20. Pattern storage tenders
21. Sand mill operators (facing, backing, and core sand)
22. Scale tenders
23. Sprue cutters
24. Steel pourers
25. Straightening press men
26. Welders

Men doing work in the occupations shown above are found in the average small steel foundry where patterns are constructed, where there is a regular gang of repair men, and where castings having good surface appearance are produced. The chief purpose in giving this list is to indicate the complex nature of steel foundry operations offering opportunities for ambitious young men to become proficient in numerous departments. In each of many of these, a good knowledge of molding and pattern making is of great value. It may be truthfully said that the electric steel foundry affords opportunities for good mechanics, for foremen, and for superintendents, which make the business much more promising than many others where apprentices are regularly employed.

Topical Questions

1. What are the essential features distinguishing an electric from any other kind of a foundry furnace?
2. What are the essentials in all processes of annealing?
3. Compare the accuracy of control possible in electric steel foundries with that possible in gray-iron foundries. What are two results to be expected from this difference?
4. Which of the finishing agencies mentioned in this chapter depend for their effectiveness upon chemical action? Upon physical action? Upon a combination?

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PART XII
MOLDING MACHINES

CHAPTER LXVI

MECHANICAL PRODUCTION IN INDUSTRY

Practically all foundries today use molding machines of one type or another. Molding machines have played one of the greatest parts in the development of the foundry industry.

They have eliminated to a marked degree the necessity for skilled men, as laborers and handymen are soon trained to operate the machines to full capacity. Consequently, the field for obtaining men is made much broader. This extensive use of molding machines, however, emphasizes rather than obviates the necessity for all-around understanding of foundry practice by a relatively few men.

The molding machine, when properly installed and operated, will develop an enormous increase in pounds of castings per molder. The largest saving is in the direct molding cost. This varies to such an extent in different shops that it is difficult to suggest any percentage which will fairly represent what may be gained.

Other benefits derived include a casting true to pattern, thereby increasing machine shop production and a saving of metal; pattern repairs are lessened; overhead per ton is lowered; rapid production is insured and grinding reduced to a minimum.

It was fitting that the great movement to *mechanize* production in American industry should have met an early response in foundries. The old-time foundry was a hard place in which to work. All this has been changed in progressive foundries and the industry as a whole is becoming known as one of the less arduous manual occupations. Contrasted with farming, for instance, the well-equipped foundry requires much less expenditure of human energy.

In every instance where labor-saving equipment has been installed, it has been found that the laborer, as well as labor

power, has been saved. It will be interesting to glance at the record of the development of labor-saving equipment in other industries. Harvey S. Firestone furnishes an excellent illustration of the effect upon tire building. The following is quoted from his book, "Men and Rubber:"

Tires are built up of plies cut on the bias. We had big tables 100 ft. long and 48 in. wide, on which the plies were cut by men with heavy knives. Two men, working hard, could make 6 cuts a minute. Now a machine makes 40 cuts a minute.

Production was increased more than six times. This meant that automobile tires could be sold to users much cheaper than before. Mr. Firestone tells how a machine was substituted for a crow bar in stripping tires. This had been hard work to be performed only by the strongest men. The stripping machine multiplied production nearly five times. In fact, it was the machine that helped to make it possible for the average citizen to enjoy an automobile. If automobiles and their accessories were produced under restrictions of unscientific management and uneconomic hand labor, only the very wealthy could afford to own or operate them.

While this was happening in the rubber-tire industry, machines were reducing costs all along the line in machine shops, sheet metal shops, furniture factories, flour mills, meat packing plants, foundries and in almost all other industries. Mr. Firestone's experiences with machines were common to all industrialists who continued in business. And best of all, the machine reduced the physical labor and increased wages. Mr. Firestone says of one old-time job: "The tires were hot, and the workmen were always blistered and sore." Then he adds that, with a machine to do the hard, hot work, "A man can do a tire a minute, practically without any physical exertion whatsoever."

Henry Ford has probably done more than any other living man to make use of machines in large-scale production. The following is taken from his book, "My Life and Work:":

"Yes, that is a very fine idea from the standpoint of the proprietor, but how about these poor fellows whose jobs are taken away from them?"

In characteristic manner, Mr. Ford admits the reasonableness of the question. He then proceeds to ask what improvements of industrial processes had ever resulted in less employment. He points out that many more men are employed on railroads than were, formerly, on stage coaches. Many times as many on automobiles as on wagons and carriages. Not only is there more employment but, what is more important, there is more potential employment.

Every improvement in industrial processes paves the way for several and sometimes hundreds of consequent improvements, all of which increase employment. When the taxicab replaced the horse cab, a hundred garages took the place of every livery stable. Likewise in the foundry, employment has been multiplied through specialization and machine production. Where the old-time molder was errand boy, laborer, and flask carpenter, there are now from three to four men in the average foundry whose work is necessary in order to carry forward production. And the end is not in sight.

There is an intimate connection between machine production and higher standards of living. How many men of 50 years ago could have 3 suits of clothes or 2 pairs of shoes? The price of a pound of automobile is not much more today than the price of a pound of steak. When wagon shops, shoe shops, and butcher shops stood side by side in every village, one wagon maker, one shoemaker, and one butcher were all that were needed by the average community of 500 people. Today, at least two shoemakers are required for repair work for 500 people. More butchers are needed merely to cut up meat. Wagon makers are still needed, and beside these are all the modern workers in occupations which have followed in the wake of machine production and specialization in industry.

The home of the average American working man is better than the home of the average well-to-do man of the days of George Washington. There are exceptions, but these will be found among working men who are employed in industries like farming and mining, where mass production with machines has not yet universally wrought changes.

Discussing his experience of getting into production, Mr. Ford says of his foundry:

Casting has always been a wasteful process and is so old that it has accumulated many traditions which make improvements extraordinarily difficult to bring about . . .

Our foundry used to be much like other foundries. When we cast the first "Model T" cylinders in 1910, everything in the place was done by hand; shovels and wheelbarrows abounded."

Mr. Ford might have added that much hard work abounded.

When a visit is made to a great, modern factory like that of Ford's Detroit plants, or any one of the great General Motors, General Electric, Western Electric, or United States Steel Corporation plants we marvel at the almost human equipment used in production. It is difficult for us to realize that much of this equipment will be obsolete within the next 20 years. But this is certain to occur.

One of the greatest forces to which man, as a social being, is subjected is illustrated by the momentum of a rapidly moving body. Momentum must be considered in production methods. Momentum must be considered in rising standards of living. The more we have, the more we want. The more we produce that we can use satisfactorily, the more we must continue to produce. There is only one thing that can happen which might change the whole trend of things. This would be the destruction of civilization and reversion to lower standards of living. This is not likely to occur very soon.

There are persons who object to specialization and machine production upon the basis that it brutalizes. This certainly is not true of the foundry industry. The machine has transformed the foundry from a mere sand-pounding place to a most remarkable laboratory of physical and chemical science.

Science plays a large part in the modern foundry, whatever the type of work. It should be understood that not all foundries feature the highly repetitive type of work carried on in the Ford plants. There are yet many foundries where castings are made according to special designs and where many highly skilled molders are required. This condition will probably continue as long as the need exists for individual designs.

Every type of molding machine is designed to do, mechanically, some of the work of molding which was previously done by hand. Some machines do the ramming, others have a mechanical draw, and others perform a combination of operations.

In order for an apprentice to be successful in a shop, it is very necessary that he learn, above all, the fundamental principles of hand molding. Molding problems, that cannot be solved by a foreman or superintendent unless the principles involved are understood, arise everyday in shops using machines.

It is most important to know the kind of machine best suited for a certain job, so that best results can be obtained. All machines have their limitations, and the foundryman must be able to judge the best type of machine for the job. There are many types of molding machines and in these chapters some typical ones will be studied separately. It is assumed that those who are studying these chapters know the fundamental principles of hand molding.

Before going further into the subject, it is just as well that the case be stated fully from both aspects. For there are two aspects to the question of more economical production through increased use of labor-saving equipment. No one has been able to improve upon this statement of this question by Frederick W. Taylor, the much misunderstood originator of modern scientific management. Writing on the subject of "Shop Management" in 1911 he said:

This book is written mainly with the object of advocating *high wages and low labor cost* as the foundation of the best management, of pointing out the general principles which render it possible to maintain these conditions even under the most trying circumstances, and of indicating the various steps which the writer thinks should be taken in changing from a poor system to a better type of management.

Here we have the two sides of the question clearly before us. *High wages and low labor cost*. There is nothing paternalistic about that. It is a question of economical production in which, through the use of more effective production methods, labor cost is reduced to the point where wages may

be raised. The formula is simple. The challenge is to every one connected with industry.

Harrington Emerson has well stated the case for mechanical progress in industry. Arguing for efficient management in 1909, he proclaims the gospel of more effective production as follows:

There are and always will be some employers whose ideal of management is to treat unfairly those under them, but the methods of efficiency will eliminate employers of this kind, even more rapidly than they eliminate the unfit and dishonest worker. Slave labor was inefficient, and it has disappeared; forced labor, *corvée*, has disappeared because it was inefficient, even from Egypt, where it flourished for 5,000 years. Child labor will be curtailed because it is inefficient . . .

Efficiency means that the right thing is done in the right manner, by the right men, at the right place, in the right time.

Whether we are animated by selfishness or by altruism, the methods, the solution, and the results are the same.

Topical Questions

1. Why does a knowledge of the principles of molding upon which a particular molding machine is based help one to operate the machine successfully?
2. Give an example of how the molding machine might increase indirect molding costs.
3. How does the molding machine assist in making a casting true to the pattern?
4. Why does the molding machine increase machine shop production?
5. How does the molding machine effect a saving in metal?
6. How does the molding machine aid in saving pattern equipment?
7. Why does the molding machine lower overhead cost?
8. How does the molding machine reduce grinding operations?
9. From a humanitarian point of view, what should be our attitude toward the installation of labor saving equipment?
10. Name some fundamental principles of hand molding which should be understood by apprentices even though they may later be employed in a production foundry where all molding is done by machinery.
11. Why do high wages depend upon low labor cost?
12. Why is the modern American factory with its mechanical development a better place to work than the average old-time shops where handwork prevailed?

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CHAPTER LXVII

HAND SQUEEZERS AND SQUEEZER PATTERN EQUIPMENT—INTRODUCTION TO THE STUDY OF POWER SQUEEZERS

The hand squeezer is the simplest molding machine. It is essentially a molders' bench equipped with a movable squeezer head, usually made to swing out of the way while the operator is filling the flask. This head is brought down against the mold by some form of toggle joint or by use of the rack and

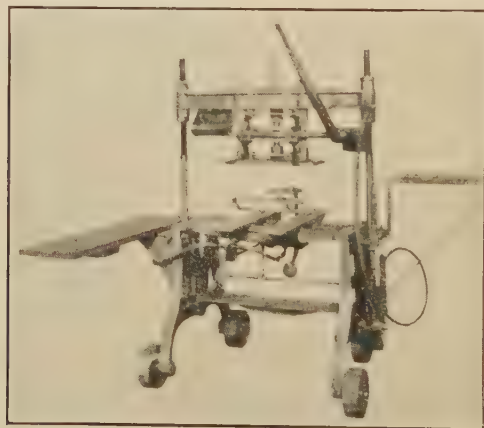


FIG. 75.—Plain hand squeezer, portable type.

pinion. This process is known as squeezing and takes the place of ramming or butting in a handmade mold. A hand lever operates either the rack and pinion or toggle joint type. This machine accomplishes, in the single operation of squeezing, what a molder does in several ramblings. Even this molding machine, simple as it is, lessens hand labor, increases production, and reduces cost. The hand machine is discussed here because of its historical significance. While

it is yet found in some of the smaller shops, it is considered obsolete in progressive foundries.

Different Kinds of Hand Squeezers.—Hand squeezers were built in stationary, portable, and straddle-leg types. The portable type was equipped with wheels which permitted it to be easily moved about the foundry thus making a foundation of any kind unnecessary. This type could also be pushed

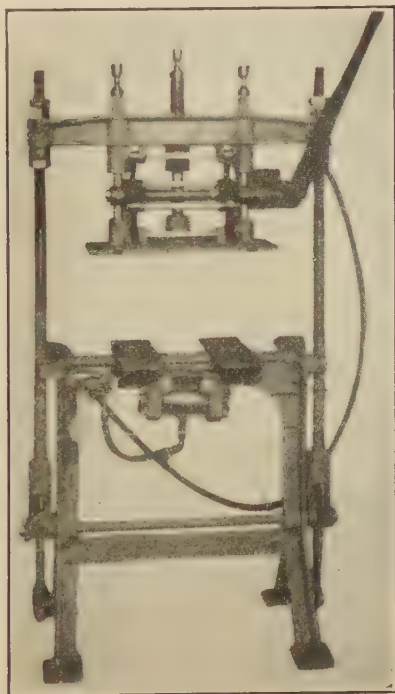


Fig. 76.—Plain hand squeezer, stationary type.

along by the side of the sand heap as the floor was filled with molds.

The stationary type was usually built so that it could be fastened by means of lag screws to a piece of timber bedded in the foundry floor. These were called post squeezers.

Machines of the type of the figure entitled hand ram, hand roll over, power draw, post squeezer have replaced the old type of post squeezer in modern foundries.

The straddle-leg type is really one form of portable squeezer. The sand is cut in a narrow windrow, and the molds dumped as the machine is pushed along, while the floor fills up. The machine moves instead of the sand. This saves considerable labor in carrying molds. This machine also saves labor in dumping the molds and cutting the sand heap even though

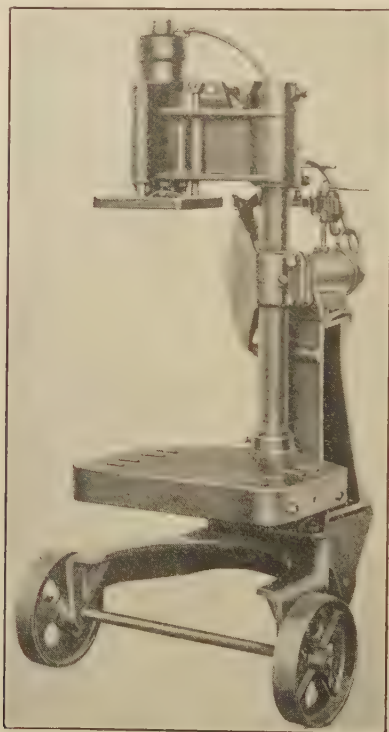


FIG. 77.—Hand ram, hand roll-over, power draw, post squeezer. (*Courtesy of Milwaukee Foundry Equipment Company.*)

a sand cutter is used. The straddle-leg type of power squeezer is in use today, for the majority of foundries now have a hard floor and there is no trouble in moving the machine as the molder works.

Duplex Squeezer.—Hand squeezers are yet built and like their successors, the power machines, they squeeze the cope and drag at one operation, the cope and drag being made side by side. The patterns are mounted on two plates, one

for cope and one for drag, so laid out from the flask pins that the cope and drag match when placed together. These machines are operated entirely by hand power and without a vibrator, if neither air nor electricity is available. One type operates by lowering the mold away from the pattern while another lifts the pattern away from the mold. This latter type is not shown. While the pattern equipment on this type of hand squeezer costs more, and there is a greater

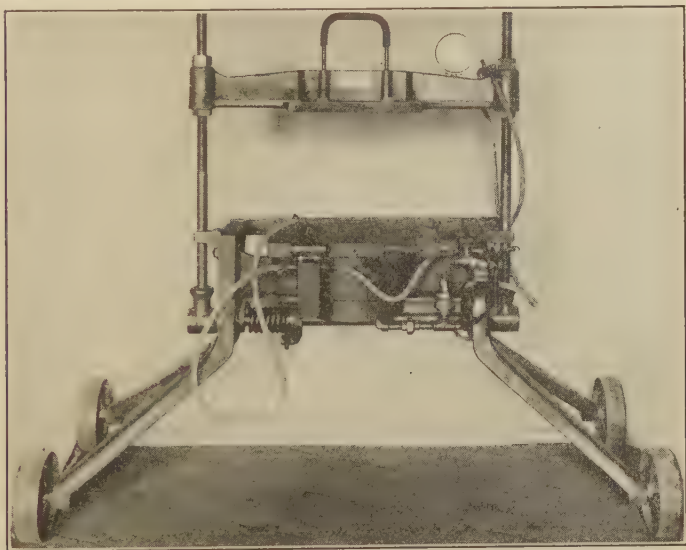


FIG. 78.—Plain power squeezer—straddle-leg type. (*Courtesy of Arcade Manufacturing Company.*)

chance for shift to occur, the production from this class of machines is large and many are in use.

Squeezer Pattern Equipment.—Pattern equipment used on hand squeezers and power squeezers is practically identical. Although power squeezers will be taken up in the next chapter, this equipment will be described in conjunction with hand squeezers.

In order for a squeezer to produce what it is capable of producing, it is of the utmost importance that proper equipment be used. Patterns must be in first-class condition and flasks should be used which will require a minimum amount

of sand in molds. Any old flask and any kind of pattern equipment will not help increase production and reduce costs.

Considerable increase in production can be made by putting on the squeezer gated patterns formerly worked on the bench. A hard oil sand match should be made for the gate, so that many thousands of molds can be made from it, if necessary

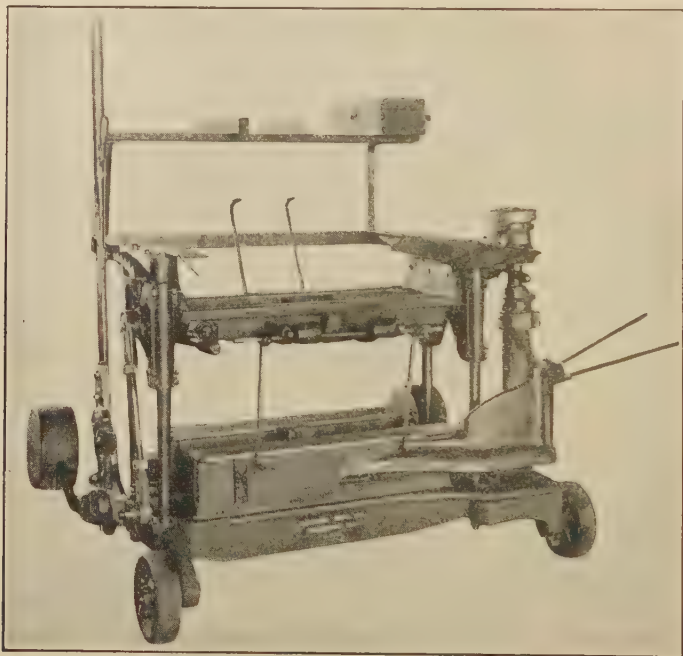


FIG. 79.—Duplex hand squeezer. (*Courtesy of Arcade Manufacturing Company.*)

without renewing the match. In this method of molding, the drag is placed on the match and rammed up and squeezed, the mold rolled over, match removed, cope put on, rammed up and squeezed. In other words, only one-half of the mold is squeezed at a time.

A better method in using gated patterns is to attach them to a vibrator frame and have a good, hard sand match made. A vibrator is attached to the frame which vibrates the patterns through the frame while the cope is being lifted and the pattern drawn. The time used in rapping the patterns by hand is

saved and a casting very true to the pattern is produced. When the pattern has a deep straight draw, the vibrator frame is quite advantageous due to the guides of the frame on the flask pins. The molding in this method is identical with that of an ordinary gated pattern with the exception of pattern rapping.

Match Boards.—Patterns are sometimes mounted on boards. Where the patterns are flat on one side, or where they are split in the center so one-half can be mounted on each side of a board, this method makes a very good and cheap pattern equipment and gives good results.

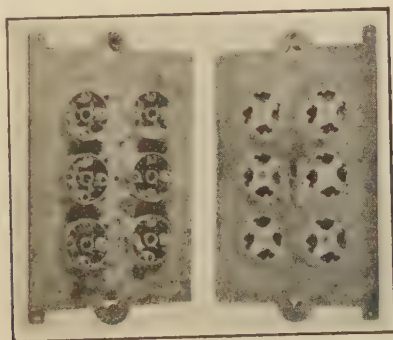


FIG. 80.—Aluminum pattern plate, pattern and plate cast together.

When molding with this equipment, the cope is placed on the machine, pattern upside down, the board placed on it with drag side up, the drag then put on the pattern so that the flask is together with the match board between the cope and the drag. The drag is filled with sand and peened, struck off, bottom board put on, and the whole mold rolled over, the cope is rammed up and the mold squeezed. In other words, the cope and drag are squeezed at the same time thus saving a squeezing operation over the method employed by use of a gated pattern. The vibrator is attached to the board and a good draw is obtained. This method of molding is used, also, when using a match plate.

Match Plates.—There are probably more aluminum match plates in use today on squeezers than any other kind of pattern equipment. The saving in pattern repairs alone in one year

often saves the price of a match plate. There is a decided increase in production over gated work and a casting exactly true to pattern results. Match plates are undoubtedly the most suitable pattern equipment that can be made for a squeezer. A match plate used on a power squeezer is probably the fastest method known for molding of small work.

The illustration below shows a match plate in the process of being made. This is a very simple operation when once understood. Any good molder can make a match plate. It will be seen that the patterns to be plated are made in the center of a mold sufficiently large to allow for 6 in. of sand on each side of the proposed plate. After the mold has been made, the skeleton frame marked *D* is placed around the patterns, then the strips marked *BB*, which are the same in

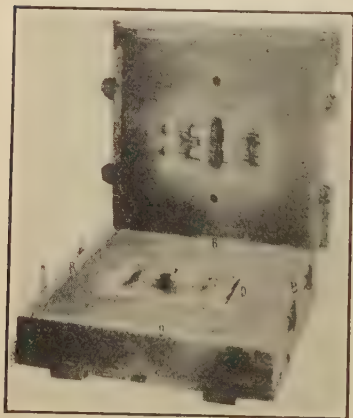


FIG. 81.—Cast match plate being made.

thickness as the frame *D* and usually $\frac{1}{4}$ in. thick, are put in place to give the desired space between cope and drag in which the plate is to be cast. The thickness of the strips will be the thickness of the plate. The intervening space is filled with sand, rammed carefully, and struck off true. The frame *D* and patterns are drawn, leaving the strips *BB* in place; the mold is closed and poured from one sprue only, the other sprue acting as a riser. If the mold has been carefully made

with fine sand, very little finishing will be found necessary. The whole operation of putting patterns on a plate, no matter how irregular the parting line may be, is simply the making of a mold in a larger flask, then separating the joint between the two parts of the mold, the thickness the plate is required. The cope half of the pattern will be reproduced on one side of the plate, and the drag half on the other. It is important that pins and bushings guiding the match plate be kept in

perfect order. Bushings should be continually examined for wear and not allowed to become loose.

Cope and Bottom Boards.—The cope board should consist of a good substantial planed board made $\frac{1}{4}$ in. smaller each way than the inside of the flask and fitted with undercut battens. A metal button should be attached to the cope board to locate the sprue hole. Bottom boards should be $\frac{1}{4}$ in. smaller each way than the inside flask measurements and should not be used when they become badly burned. In molds that require little peening, time is saved by putting peening strips around the outside edge of the boards. These strips are triangular in shape about $1\frac{1}{4}$ in. high and $\frac{3}{4}$ in. on the side next to the board. These peening strips serve to squeeze the sand much harder around the outside of the mold and make peening by hand or shovel handle unnecessary.

Flasks.—The snap flasks should be the best obtainable. They should be well made and rigid, with good hinges and catches. Old, loose-jointed, "wobbly" snap flasks do not prove profitable. Snap flasks are built both tapered and straight sided. In some cases, where pouring jackets are not needed, the straight snap flask is still used, but in most cases tapered flasks are used with steel pouring jackets made by the manufacturer of the flask. Wooden jackets made by the foundry carpenter usually fit the first few times they are used, and then the wood becomes distorted and the jacket is either too loose or too tight. Many dollars can be saved in foundries by either a steel or cast-iron pouring jacket which is manufactured by the firm making the flask, thus insuring the correct taper and a positive fit.

Of late years, the use of aluminum tapered snap flasks with steel or cast-iron jackets has become very popular. Many foundries are adopting them in place of wood snap flasks due to their rigid construction and the manner in which they leave the mold. Instead of having hinges and catches, they are built with a sand strip which is made so that by a simple operation it is moved out of the mold and into the flask. The flask is then lifted off the mold. This saves the time spent in opening and closing the flask. This type of

flask is used, also, in conjunction with split pattern equipment for jolt stripping machines.

As a general rule 12 by 18 in. is the largest snap flask that is profitable on a squeezer and 10 by 18 in. is a better size. If the flask is only 8 or 10 in. wide, it can be as long as 24 in.

In square sizes, 14 in. square is about the limit, and again one 13 in. square will give better results; 12 by 14 in. and 12 by 16 in. are good workable sizes.



FIG. 82.—Aluminum tapered snap flask with jacket. (Courtesy of The American Foundry Equipment Company.)

Much larger sizes of molds can be squeezed but, as a rule, the size is limited by the weight of the mold a man can carry without having it come in contact with his body; for if it touches the man while being carried to the floor, shifts are almost certain to result. In hand molding, the board extends beyond the mold and no harm is done if it is rested against his body.

As the number of patterns in the mold has no influence on the number of molds made, it is a distinct advantage to have the mold as full as possible.

Vibrators.—There are two kinds of vibrators used on squeezers. One is operated by air, the other by electricity. The vibrator is fastened to the plate or pattern frame and operated by a knee valve so both hands of the operator are free. This insures a good draw and no broken edges to patch. Most air vibrators are arranged so that the amount of air entering the vibrator can be controlled. Often on deep draws or where small pockets are lifted in the cope, too much vibration breaks them off.

Sprue Cutters.—A good tubular sprue cutter should be provided for each squeezer. Using an old bent sprue cutter that holds the sand, thus making several attempts necessary before the sand can be dislodged, is not economy. A piece of brass tube the proper size makes a good sprue cutter.

Sprue Patterns.—Sprue patterns may be inserted into holes in plates. The sprue pattern is provided with a projecting pin at the bottom with sufficient shoulder to allow the pattern to rest squarely upon the plate. The pin should be at least $\frac{3}{4}$ in. in diameter to prevent the pin being bent under pressure. The use of sticks with nails for pins is very bad practice.

Hard Sand Matches.—The hard sand match is considered by foundrymen to be the best match that can be made. If it is carefully made, it will produce many thousands of molds. To make a hard sand match, bed the pattern, or gate, or patterns in the drag in the usual way. Be sure the parting line is correct in all places. Oil the pattern well to prevent its sticking. Riddle enough dry, well-burned parting sand through a No. 30 riddle, to make the match. This parting sand should be composed of very fine particles but should not be dust. Mix thoroughly in this sand about a tablespoonful of litharge.

After the litharge is evenly mixed through the sand, temper the sand with boiled linseed oil to about the temper of molding sand. Protect all corners and places that will be exposed to greater wear, by placing screw heads down in the corners and exposed places. Nail heads or strips of metal can be used. These should be carefully placed against the pattern as the pattern lies in the drag. Place, on the drag, a wooden frame made of sufficient depth to cover the exposed pattern. Riddle,

carefully, sufficient oil sand on to the pattern to hold the nails and screws in place. Tuck carefully with the fingers around the pattern so as to pack the sand next to the pattern, particularly all corners and pockets. Fill the frame with the sand and ram snug, even a little harder than if you were making a mold. Strike off the frame and screw the bottom board on to the frame. Roll over the match and drag and remove the drag flask. Carefully remove the molding sand with bellows taking care not to disturb the oil sand. Smooth off the face of the match with a trowel and rap the pattern sufficiently to give a little clearance.

Place the match some place where it will not be disturbed and where it will keep warm, but not get too hot, and leave it for 12 hours. It should then be quite hard and the pattern can again be rapped and removed. When thoroughly dry, the face of the match should be shellacked. It is then ready for use.

The hard sand match is worn out by the molder's being careless in placing the pattern in the match. If he is careful to drop it squarely in place, the edges last a long time; but if he places it on the face of the match and slides it into place, the edges are quickly worn off unless fully protected. A good way to prevent the quick wearing of the match is to drill two holes through the runner and insert pieces of brass rod to nearly fit the holes. These pieces of rod should be inserted in the holes in the runner, when the match is made, so that they will be imbedded in the match. When the molder puts the patterns in the match, it is necessary to engage these pins and the pattern drops into the match without touching the edges.

Molding Machines Should Be Cleaned.—Molding machines should have proper care after each day's work. They should be cleaned, all sand brushed off and the machines oiled. This takes only a few minutes and pays well. They become hard to operate unless cared for each day. The foundry is a hard place for machinery and the only way to get good service is to use proper care.

Topical Questions

1. Why may the hand squeezer be said to be the simplest molding machine?
2. Describe the hand process which is replaced by squeezing.
3. Why does the operation of a hand squeezer require less human energy than the hand method of making similar molds?
4. Describe the respective molding conditions under which each of the three types of hand squeezer is used.
5. When is the mechanical draw better molding practice than the hand draw?
6. Why is the jarring type of squeezer better adapted for deep work?
7. List seven different kinds of pattern equipment used on squeezers.
8. What kind of pattern equipment should be used to produce castings whose parting line surfaces are to be nicked and buffed?
9. What are the principal differences between the molding operations incident to the use of (a) gated patterns; (b) match plates?
10. What are the more important details to be considered when making flasks to be used in casting match plates?
11. Why should cope boards be absolutely straight?
12. What will happen when burned or weak bottom boards are used? Why?
13. What are some advantages of a tapered snap flask over a straight snap flask when using pouring jackets?

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2. "Report of Joint Committee on Pattern Equipment Standardization," *Transactions of the American Foundrymen's Association*, Vol. XXXV, 1927, pp. 95–100.
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CHAPTER LXVIII

POWER SQUEEZERS

Power squeezers are operated by compressed air. It is therefore necessary to have an air compressor before installing power squeezers. Few foundries today, however, are without compressed air as it is indispensable in a modern foundry. Chipping hammers, air hoists, shakeout vibrators, and many other foundry machines are run by means of this power.

There are so many types of power squeezers that it will be necessary to classify them for the purpose of description.

Type I.—Plain power squeezer with head swinging on rocking strain rods.

Type II.—Plain power squeezer with rotating head on column and with or without tension rod to take part of the strain when head is in place, swing head type.

Type III.—Power squeezer, split pattern type with heads of Types I and II.

Type IV.—Power squeezer stripping-plate machine with heads of Types I and II.

Type V.—Plain power jolt squeezer with heads of Types I and II and with horizontal swing head.

Type VI.—Power squeezer jolt ram split-pattern machine with heads of Types I and II.

Type VII.—Power squeezer jolt ramming stripping-plate machine with heads of Types I and II.

Type VIII.—Carriage or conveyer type molding machine.

Power squeezers, like hand squeezers, are adapted for work known as bench work. The greatest advantage they have over hand squeezers is the saving of physical exertion required in squeezing on a hand machine, thereby increasing production.

Type I. The Plain Power Squeezer with Head Swinging on Rocking Strain Rods.—This machine operates practically the same as a hand squeezer except that the squeezing is

done by letting air into the cylinder forcing the mold up against the head. The cylinders are usually 10 or 12 in. in

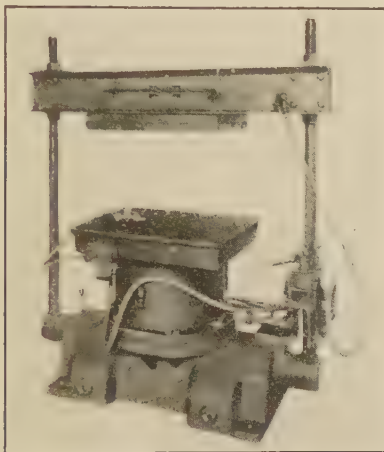


FIG. 83.—Plain power squeezer, low trunnion type.

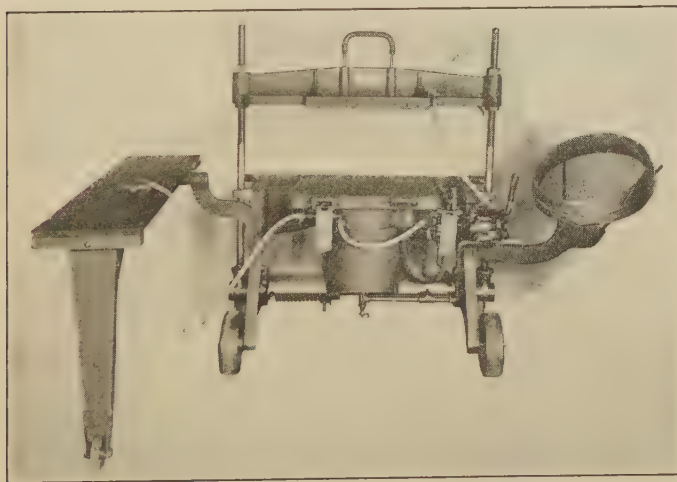


FIG. 84.—Plain power jolt squeezer, portable type. (*Courtesy of Arcade Manufacturing Company.*)

diameter. This type of machine is designed to operate efficiently at 80 lb. air pressure. The air should be let into the cylinder slowly enough to avoid giving a ramming blow as

the steady squeeze is much better. After the mold is squeezed, the air is exhausted by a turn of the valve lever and the table returns to its former position. An attachment used to advantage on these power squeezers is a blow-off valve releasing the air at a desired pressure, thus assuring uniformity of density of the mold.

The plain power machine is adapted for use on gated or single patterns on hard matches, patterns in vibrator frames,

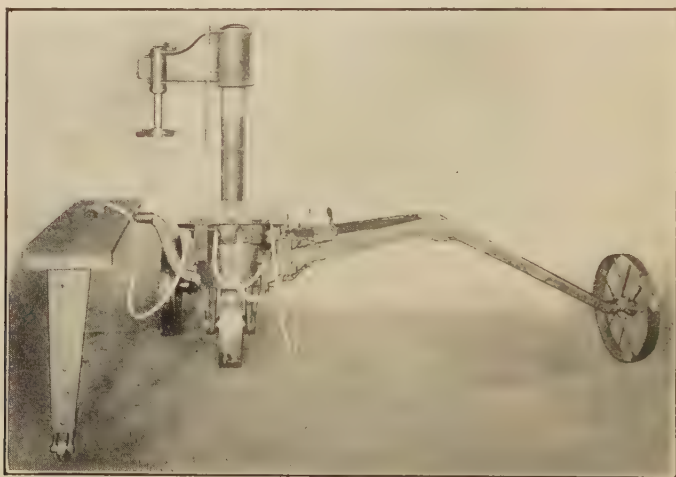


FIG. 85.—Plain power jolt squeezer with straddle legs. (Courtesy of Arcade Manufacturing Company.)

patterns mounted on one or both sides of boards, patterns mounted on one or both sides of metal plates of steel, cast iron, or aluminum, and so-called squeezer plates where the patterns and plates are cast in one piece. The three latter methods give better satisfaction and greater output.

Another machine of this type is shown in the illustration on the preceding page of a jolt squeezer portable machine.

This type of machine is also built with straddle legs to enable the machine to straddle the sand pile. This construction is particularly advantageous when the floors are long and narrow as it reduces greatly the distance the operator is obliged to carry his molds. After pouring, the molds are dumped in a windrow, and the sand is tempered and cut in

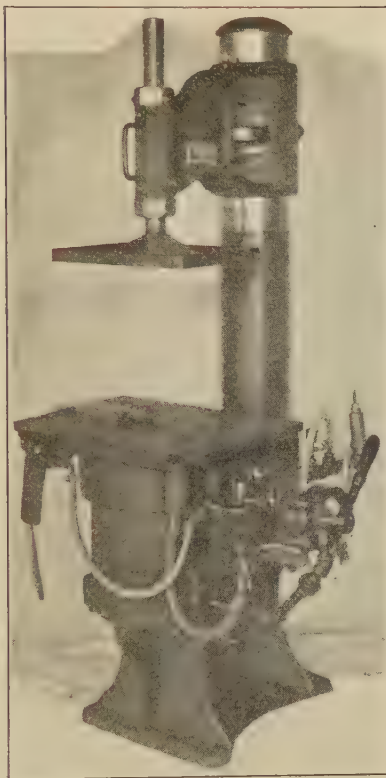


FIG. 86.—Plain power squeezer with rotating head. (*Courtesy of Arcade Manufacturing Company.*)

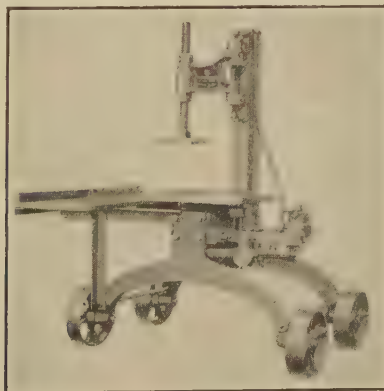


FIG. 87.—Portable type jolt squeezer. (*Courtesy of The Johnson and Jennings Company.*)

this position for the next day. This is a considerable saving in labor in dumping and cutting the sand.

Type II. The Plain Power Squeezer with Rotating Head.—This differs from Type I in that the head swings horizontally out of the way instead of rotating on strain rods. The head is swung around easily into place. The same pattern equipment is used on this type as on the type having the swing head on rocking strain rods.

The pressing block has a steel adjusting screw permitting easy adjustment of the block for various depths of molds.

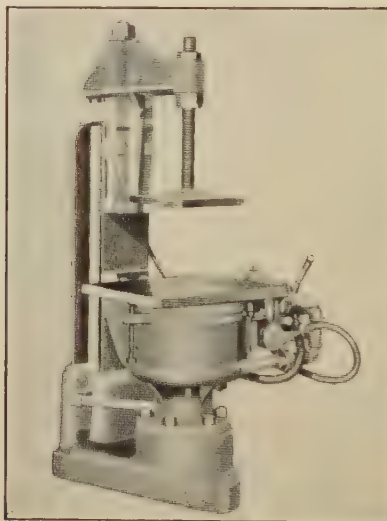


FIG. 88.—Stationary type jolt squeezer. (Courtesy of The Johnson and Jennings Company.)

Less clearance is required between the bottom boards and the pressing head in this type of machine than is the case with the Type I machine.

Type III. Power Squeezer—Split-pattern Type.—These machines are built with heads of three kinds: The head swinging on rocking strain rods, the rotating head, and the head mounted on a carriage.

As its name indicates, this third type is used where the patterns are split and mounted on plates, a plate being provided for both the cope and drag unless the patterns are

the same in cope and drag, or where the transfer method is used, in which case a single plate is sufficient. This kind of machine has long been in use and is one of the first types of power squeezers made.

Unlike the plain power squeezer operated with match plate, these machines make only one-half of a mold at a time. They are used in both iron and brass foundries and are used with snap flasks or solid flasks, according to the

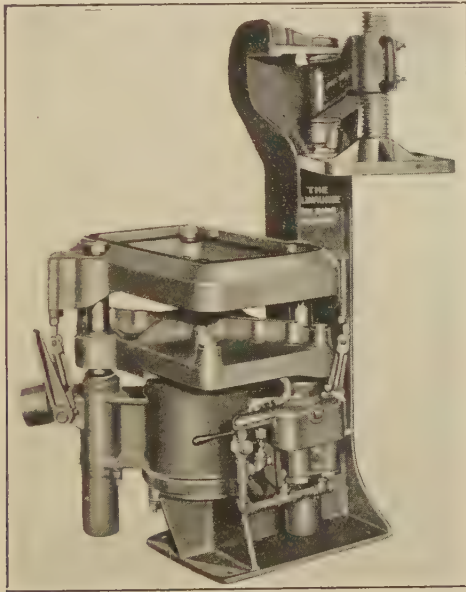


FIG. 89.—Power squeezer—split pattern type. (Courtesy of Milwaukee Foundry Equipment Company.)

nature of the casting. Agricultural castings, fittings, valves, and other work of such character have long been produced on machines of this type. It is provided with a pattern drawing attachment which operates to lift the mold from the plate.

Stools may also be used to support any particular core or hanging body and the stool is lifted as the mold is raised, thereby supporting the core or hanging body. The pattern drawing attachment is arranged to operate with hand lever, oil operated valve, and air pressure. Stools are discussed under the subject of stripping plates.

Type IV. Power Squeezer Stripping-plate Machine.—

This type of machine is built with head swinging on rocking strain rods, the rotating head type, or with the head mounted on a carriage. In fact, any split-pattern machine can be fitted with stripping-plate patterns without difficulty.

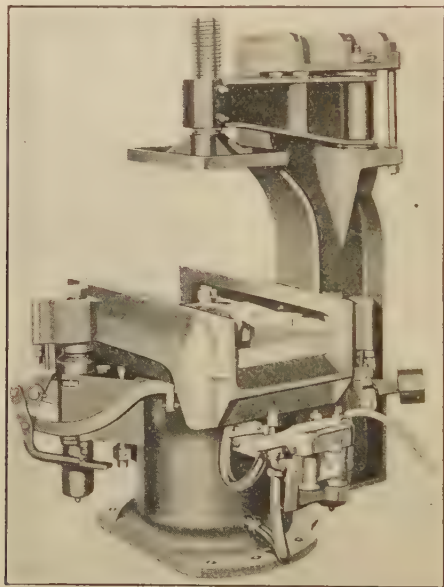


FIG. 90.—Power squeezer stripping plate machine. (Courtesy of Milwaukee Foundry Equipment Company.)

Type V. Plain Power Jolt Squeezer.—The principle of jolt ramming the sand has been applied to power squeezers with the head swinging on rocking strain rods, the rotating head type, and the head mounted on a carriage. This character of machine is adapted for use with the same pattern equipment as mentioned in the plain power squeezer Type I and is particularly adapted for deep drag, shallow cope work mounted on plates. The drag is jar rammed first, the board is put in place, and the cope is then squeezed but not jar rammed. This jarring principle does away with all tucking by hand, rams deep green sand cores perfectly, and produces castings true to pattern.

The jolting increases the capacity of the machine as deeper flasks can be rammed than can be squeezed. In fact, many foundrymen believe that production can be increased with a jolt squeezer over a plain squeezer on almost any kind of a plate job. On a shallow light job on a jolt squeezer, it is unnecessary even topeen. The drag is filled with sand, jolted two to three times, the board is placed and the mold is rolled over. Then the cope is squeezed as usual.

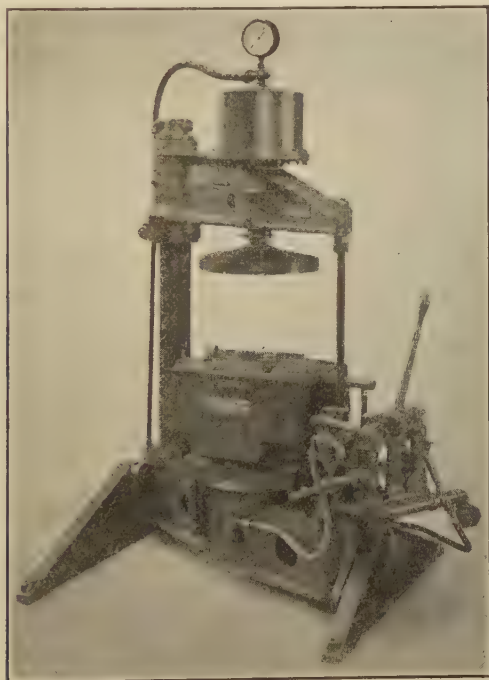


FIG. 91.—Plain jarring, squeezing, flask lifting machine, with 10-in. squeezing cylinder. (Courtesy of The Tabor Manufacturing Company.)

Type VI. Power Squeezer, Jolt Ram, Split-pattern Machine.—This type of machine is an application of the jolt ramming principle to the split-pattern machine and is built with the same heads as mentioned in describing the split-pattern machine. The application of the jolt ramming principle is a distinct advantage, as nearly every one knows the increase in production by jolt ramming.

This feature is added to the machine by the use of a valve which raises the table to a certain height when the valve releases, allowing the table to fall and strike an anvil or what serves as an anvil. Some makes of machines apply this principle by use of a cylinder inside the ramming cylinder.

Type VII. The Power Squeezer, Jolt-ramming, Stripping-plate Machine.—This type of machine is built with heads

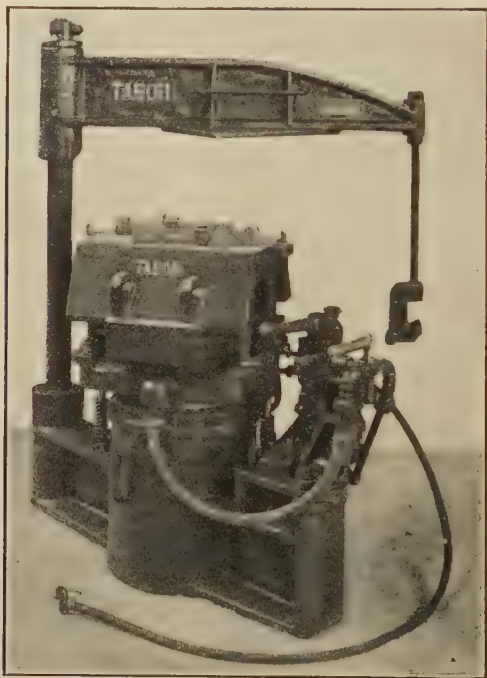


FIG. 92.—Shockless jarring, squeezer, flask lifting machine, with 13-in. squeezing cylinder. (Courtesy of the Tabor Manufacturing Company.)

mentioned in Types I and II. The machine has the combination of jarring the mold, squeezing the board in place, and stripping the pattern; and it accomplishes all these operations in a rapid and efficient way.

Castings of the most exacting character can be produced on this machine. To get the best results, it is necessary that the machines be kept in good order and the pattern equipment be such as to make a perfect mold.

Type VIII. Carriage Molding Machine.—The carriage or conveyer type of molding machine is made use of in many production foundries. It is used quite extensively in the production of automobile castings. The advantages of this machine for high production work are obvious. The first of the four following pictures shows a 33-54 type *D* combina-

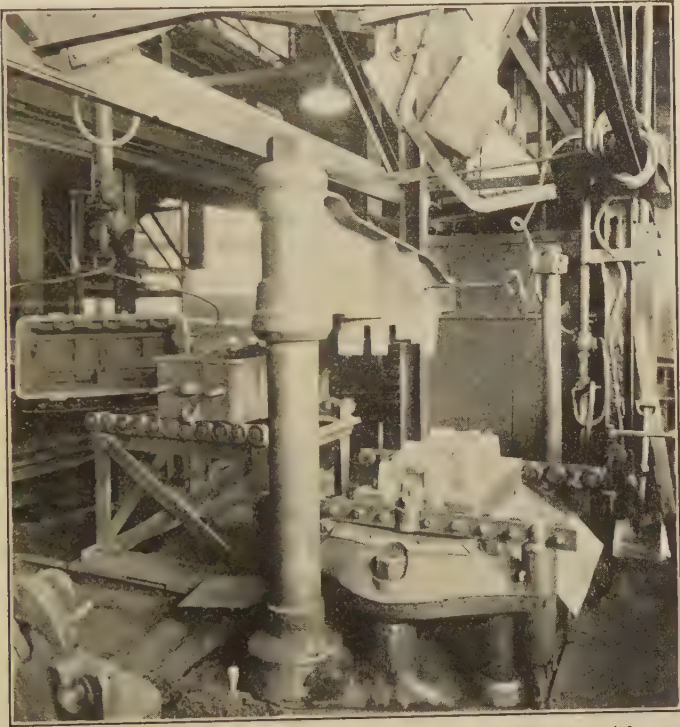


FIG. 93.—33-54 Type D combination jolt and power squeezer with pattern draw and flask roll-off attachment. (Courtesy of Wm. H. Nicholls Company, Inc.)

tion jolt and power squeezer with pattern draw and flask roll-off attachment. This machine has a 33-in. squeeze piston, 13-in. jolt piston, and is 54 in. between the uprights. The weight is approximately 19,000 lb. It is used for making large 4- and 6-in. cylinder blocks and other production castings. Hudson, Essex, Oldsmobile, and Buick cylinders are made on this machine. The capacity is 350 to 450 molds

3. State whether or not, in your opinion, an automatic shut-off valve is advantageous in operating a power squeezer. Give reasons for your opinion.

4. Indicate the types of squeezers which, in your opinion, should be used for molding the following articles: (*a*) small tooth gears; (*b*) stove legs; (*c*) small valves; (*d*) gated patterns; (*e*) lamp bases. Give reasons in each case.

5. What are the advantages of the straddle-leg squeezer over the stationary squeezer? Disadvantages? When should the stationary squeezer be used?

6. What precautions should be taken with pattern equipment on a split pattern machine?

7. What molding operation performed on squeezers should be taught first to inexperienced operators? Why?

8. What are the more important details to be considered when changing the height of the head of a squeezer? What is the most important detail to consider in this connection when beginning a run of molds? Give reasons in each case.

9. How does the use of a jolt squeezer affect the use of sand? What operations are affected? Why?

10. What precautions should be observed in piping compressed air to squeezers? Why?

Reading References

1. FORD, HENRY, and CROWTHER, SAMUEL, "My Life and Work," "Machines and Men," Chap. VI.

2. MOLDENKE, RICHARD, "Principles of Iron Founding," "Modern Foundry Advance," pp. 18-21.

CHAPTER LXIX

STRIPPING PLATE MACHINES AND RIGGING

History of Stripping-plate Machines.—The idea of drawing the pattern through a plate is a very old one. The illustration below shows a pair of the first machines built.

There were several reasons for the success of the stripping plate machine:

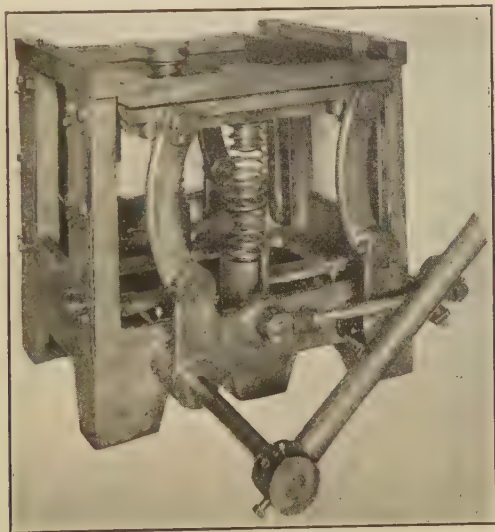


FIG. 97.—Double shaft stripping plate machine. (*Courtesy of Arcade Manufacturing Company.*)

1. A remarkable increase in production over the hand method of molding.

2. Unskilled laborers could be quickly taught to operate them, thus decreasing the need for skilled mechanics on jobs which could be done with this equipment.

3. The quality of the work produced on these machines was far superior to any produced by hand. Implement

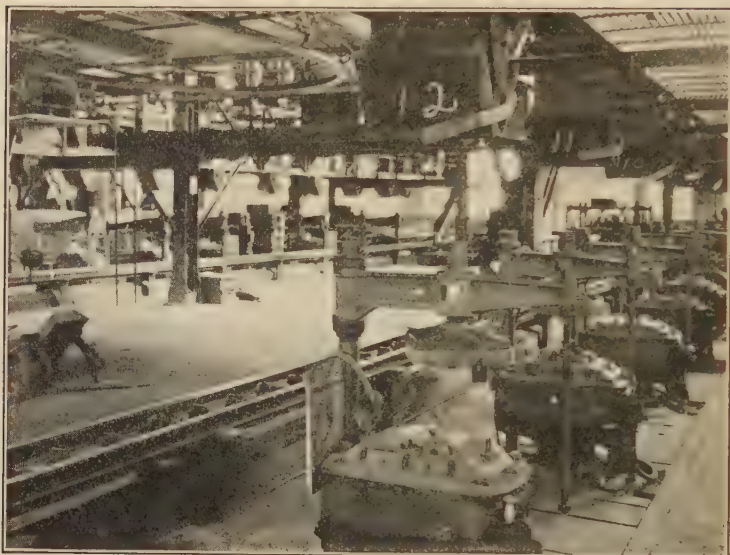


FIG. 94.—11-32 Heavy duty type D combination jolt and power squeeze molding machines. (Courtesy of Wm. H. Nicholls Company, Inc.)

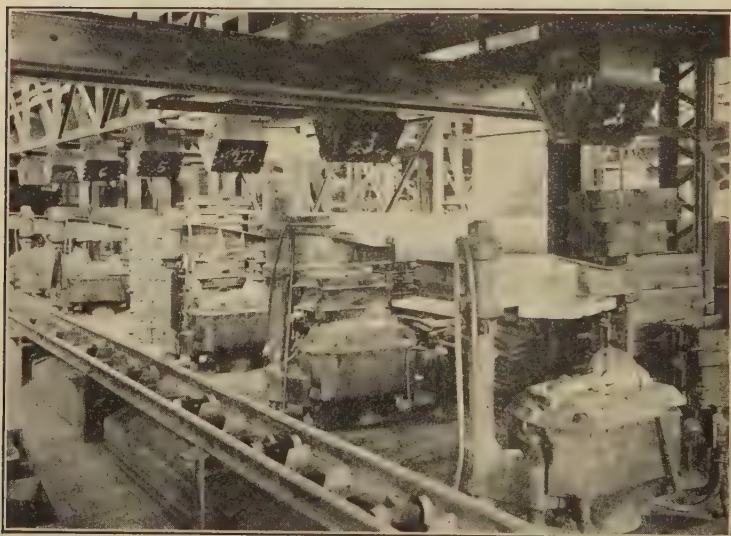


FIG. 95.—14-36 Heavy duty type D machines making large Buick carriers at one of the General Motors Corporation's foundries. (Courtesy of Wm. H. Nicholls Company, Inc.)

a day from one pattern equipment. The second illustration shows part of an installation of 11-32 heavy duty type *D* combination jolt and power squeeze molding machines with pattern drawing device at one of the large automobile foundries. This 11-32 type *D* machine has a $11\frac{1}{4}$ -in. squeeze piston, $5\frac{1}{4}$ -in. jolt piston, and is 32 in. between the uprights. It weighs approximately 1,500 lb. The third illustration shows a line of 14-36 heavy duty type *D* machines making large Buick carriers at one of the General Motors Corporation's foundries. This machine has a 14-in. squeeze piston, 6-in. jolt piston, and is arranged for pattern draw of 2, 4, or

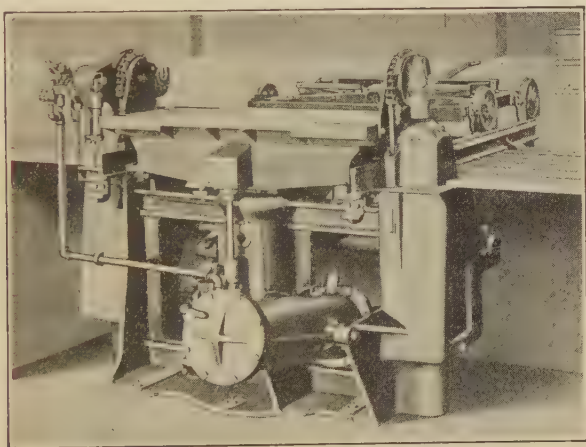


FIG. 96.—Power jolt roll-over pattern draw molding machine equipped with carriage. (Courtesy of The Osborn Manufacturing Company.)

6 in. It weighs approximately 3,100 lb. The fourth illustration shows a power-jolt, roll-over pattern draw molding machine equipped with carriage. This type of machine is used to a great extent in production foundries.

Topical Questions

1. Why is compressed air, which is one of the more expensive mediums of power, preferred for operating molding machines? In answering this question, consider what other mediums of power might be used instead of compressed air.
2. Name several operations eliminated through use of power squeezers instead of plain hand squeezers.

manufacturers and dealers had long been annoyed by the fact that extra parts furnished by them for machines, would not always fit into place but required filing and fitting by the farmer. No two molders rap a pattern exactly the same, nor do any two ram alike, and the resulting castings had almost always to be fitted into place. With the stripping plate in use, it was at once found that the castings came true to pattern and that at last a way had been discovered to produce castings that were always duplicates.

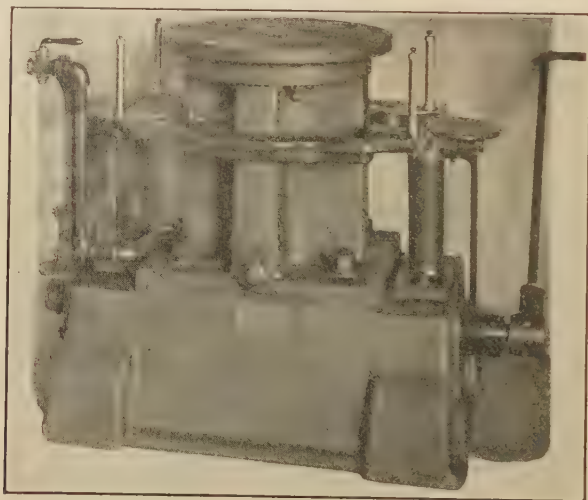


FIG. 98.—6" Portable jolter with 6" hand strip. (Courtesy of Arcade Manufacturing Company.)

4. The economy resulting from improved quality, greater production, and the employment of less skilled men was so great as to be almost unbelievable. On 15 patterns made by the McCormick Harvester Company at the time the stripping-plate machine was introduced, the reduction in cost of molding by using this machine was 75 per cent. It is no wonder, then, that the stripping-plate machine was rapidly adopted. Today, you can scarcely visit a foundry that has not at least one pair of stripping-plate machines in its equipment, and many large foundries turn out 90 per cent of their castings on them.

The plain stripping-plate machine performs only one operation in the making of a mold, that is, drawing the pattern from the sand. Unless the casting to be made is symmetrical with the parting line, it is necessary to have a complete cope and drag pattern equipment. The pattern equipment consists of a half-pattern or patterns mounted on a plate usually made of cast iron. Another plate, called the stripping plate, is cut out so that the patterns will drop through it. The contour of the opening in the plate is exactly that of the pattern at the parting.

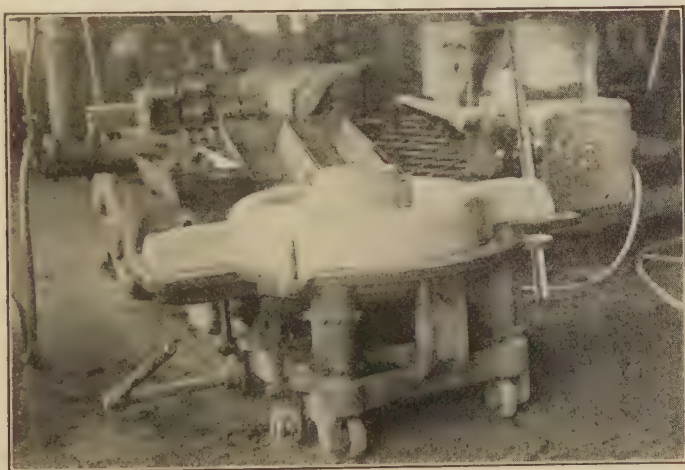


FIG. 99.—Hand ramming, hand stripping plate machine. (Courtesy of *International Molding Machine Company*.)

The stripping plate machine consists of a strong stiff frame, having two or more sets of adjustable guide ways in and near the top of the frame, on which the stripping plate is supported, while in the base of the frame and at a comparatively great distance from the upper guide ways there is a single, centrally located, brass-bushed guide way. This construction gives, in effect, a long, rigid guide way in which the yoke carrying the pattern or patterns is raised and lowered by means of a depending connection, crank, shaft and lever, or by a single lever.

The crank shaft is journaled in a long brass bushed box, either cast with or firmly secured to the bottom of the upper

frame. The yoke is held in its highest position in which the sand is rammed in the flask by a crank pin passing slightly beyond the center and striking a stop, or by some similar locking method.

The simplicity of the machine is one of its greatest points, for today there is no type of machine that requires less care and that costs less to maintain than the stripping-plate machine. If the patterns are properly made, mounted, and watched, the machine is always ready for production.

Rigging.—As much depends upon what is usually termed the “rigging” as upon the machine and pattern, so a great deal of study is necessary to have the flask, gate, sprue, crane, hoist, bail, and other parts of the rigging as nearly perfect for the job in hand as they can possibly be made.

Flasks.—The matter of flasks is a vital one, for upon the flask depends, largely, the success of the job.

The flask should conform as nearly as possible to the shape of the pattern so no surplus sand will have to be rammed. It should have the joints machined true so it will not rock on the plate; and all flasks should be absolutely interchangeable. Binding pins or loose-fitting pins must not be tolerated. The flask must fit the machine without the slightest movement; and when rammed with sand, it must be lifted off without the pins binding or sticking in the slightest degree. All flasks should be provided with a sand strip or lip around the joint edge.

Flasks that require bars should be carefully studied in order to place the bars so as to support any body of sand that is nearly cut off and lacks support. If the flask is properly barred, in nearly every case the use of “soldiers,” gagers, nails, etc., will be unnecessary. The bars must follow the contour of the pattern and should come to within about 1 in. of the pattern and joint. If the bars come too close to the pattern, it makes tucking necessary to prevent soft spots under them.

The drag must be barred as well as the cope. In making an iron flask that has bars, it should be molded so that the joint of the flask is the joint of the mold. When the mold is made in this way, the sand will naturally wedge into the

spaces between the bars, and if the mold is turned over the sand can be shaken out with little effort. The flask will not crack easily if the corners are rounded instead of square.



FIG. 100.—Fly wheel pattern.

The Gate and Sprue.—The gate should be made of metal and carefully fitted to the plate and against the pattern so no sand can get under the gate or between the gate and pattern.

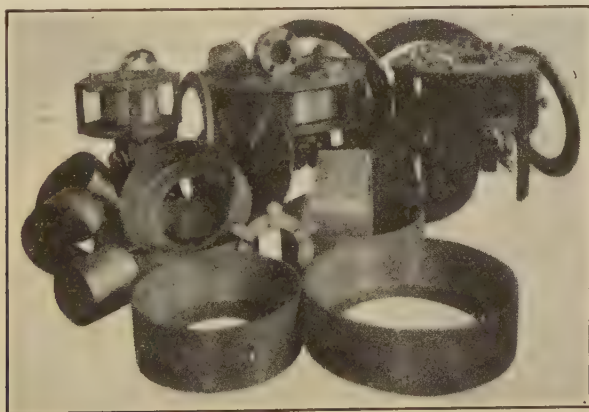


FIG. 101.—Pulley machines and patterns.

The sprue should be made of metal, preferably iron or brass, of proper size and shape, and so designed as to make the sprue and pouring basin in one. When the sprue pattern is drawn out, the hole should be clear through the cope and the sand should be well rammed all around the basin and

sprue. A good way to insure a sprue hole that does not have to be blown out or cleaned is to drill a $\frac{3}{4}$ in. hole completely through the stripping plate where the sprue sets. The bottom end of these sprues should be turned with a shoulder to set squarely in the hole in the stripping plate.

The best metal to use for stripping plate patterns is cast iron. This metal requires a little more care to keep clean and polished but well repays for the extra care.

Where the job requires a bottom board it should be made substantial with strong battens so placed that the board will

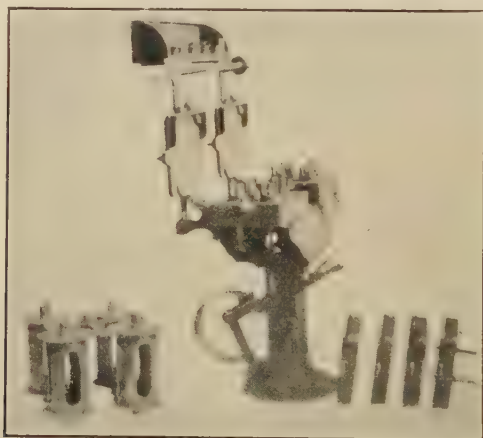


FIG. 102.—A "four-part" job fitted to one machine.

not spring if the floor is uneven and thus cause a crooked casting. The clamping of the board should be quickly done and secure.

Cranes.—The crane carriage should run free and not cramp on the runway. Cranes moved by hand chains are too slow for ordinary stripping-plate work.

The ideal is a crane that is run easily by the molder's pushing on the load and that does not bind or cramp in the least, even when the load is at one end of the carriage. Such carriages may cost more but are nevertheless more economical.

Many stripping-plate jobs have been made slower by taking a job that can be handled by hand and putting two pieces in a flask and making it a crane job. More pieces can

be made where the job can be handled by hand than can be made by doubling up, if the job has to be handled by a crane.

Combination Machines.—The machine using the principle of drawing the pattern through a stripping plate has been combined with other types of molding machines, and we find the stripping plate used on power squeezers, split pattern, roll-over machines and jarring machines. In every instance, the stripping plate gives better quality and more economical production.

The Jar Stripping-plate Machine.—The combination machine using the jarring principle to ram the sand and the



FIG. 103.—Jolt ramming, hand stripping machine. (Courtesy of International Molding Machine Company.)

stripping plate to draw the pattern embodies two of the most useful principles so far adapted to mechanical molding.

The jar-ram, stripping-plate machine consists of a jarring machine upon the table of which is mounted the pattern. Around the pattern is the stripping plate. When the pattern is drawn, four posts are forced up engaging the stripping plate at the corners, thus raising the mold and plate and drawing the pattern. This combination machine has proved to be very fast and requires little physical effort on the part of the operator. Patterns that have long, continuous runs are well adapted to this class of machine, particularly if the mold is deep or quite large in area. The jarring machine rams a large, deep mold nearly as quickly as a small mold so

the saving in time and physical effort is much greater on the larger size molds.

It has been found advantageous to change many plain stripping-plate jobs to a jar-ramming, stripping-plate machine because the physical effort on the jar-ramming, stripping-plate machine is less. The operator has only the handling of the sand and of the molds from the machine.

This type of machine requires less skill to operate than is required on a plain stripping-plate machine. The sand being rammed by the machine, very little skill in ramming is necessary on the part of the operator. The sand is rammed much more evenly by this machine than can be done by hand, even by a fairly skilled man. Although small flasks can be rammed nearly as quickly by hand as by machine, there still remains the disadvantages in hand ramming of the physical effort required from the operator and of the difference in necessary skill.

In making patterns and stripping plates for this type of machine, it must always be kept in mind that there can be no give or spring on the part of the patterns, plate, or stool when the mold is being rammed. It should be kept in mind also that the force of the blow is considerable. The plate must be very substantially built, for if any spring does occur a false parting is created in the sand.

Metal Bottom Boards.—Metal bottom boards are coming into more general use because the metal board does not have a tendency to spring, warp, or burn out. Metal boards assure true bases and result in equalization of support, thus aiding in the production of true castings.

Topical Questions

1. State four reasons for the success of the stripping plate machine.
2. Which do you consider the most important? Why?
3. What difficulties in molding did the stripping-plate machine overcome?
4. What precautions are necessary in using the same pattern for both cope and drag? State reasons in each case.
5. Can snap flasks be used successfully on a job of this type? Why?
6. What kind of a gauge or template should be provided on a job where the cope and drag patterns are one and the same thing?

7. What is meant by the "contour" of a pattern as related to a stripping plate?

8. What is meant by a pattern being symmetrical with the parting line?

9. What is the yoke on a stripping-plate machine? How does it function?

10. What precautions should be taken to keep the flask from rocking on the plate?

11. How is the quality of castings affected by soft spots in the sand under the bars of a flask? Explain.

12. What special precautions should be taken in designing a pattern of a mold of a barred iron flask to prevent dropped copes or rats?

13. Give some reasons why cast iron is a practical metal from which to make a stripping-plate pattern.

14. What two principles are involved in the jarring, stripping device?

Reading References

1. FIRESTONE, HARVEY S., and CROWTHER, SAMUEL, "Men and Rubber," "Can it Be Simplified?" Chap. IX.

2. GRAY, BURTON L., "Foundry Work," Rev. Ed., 1920, "Use of Molding Machines," pp. 67-88.

3. MILLER, FRED J., assisted by FERGUSON, WILLIAM B., "Waste in Industry," "The Metal Trades Industry," Chap. IX.

CHAPTER LXX

ROLL-OVER, JAR-RAMMING, AND PATTERN-DRAW- ING MACHINES

There are two major operations in the making of a mold, ramming the sand and drawing the pattern. The minor operations consist in clamping on the bottom board, rolling over the drag, setting cores if any are used, and closing the mold. The more operations both major and minor which

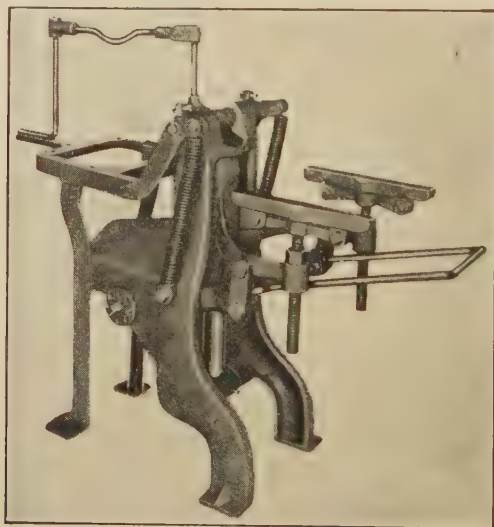


FIG. 104.—Plain roll-over draw machine. (*Courtesy of Milwaukee Foundry Equipment Company.*)

can be done mechanically by a molding machine, the more the production will be increased and costs decreased over the hand method of molding.

There are many types of roll-over, draw machines some of which do, mechanically, most of the molding operations. The type of machine to use on a job depends on the class of work

and number of pieces to be made, so that it is impossible to make any set rule.

The plain, hand-roll-over, draw machine can often be used to great advantage in the foundry. It performs one major and two minor operations in a mechanical way as the bottom board is clamped in place, the mold rolled over, and the pattern drawn mechanically. The value of this machine lies in the



FIG. 105.—Plain roll-over draw machine in core room. (Courtesy of International Molding Machine Company.)

fact that the machine is adapted to a large range of work, patterns are quickly changed, and the mold is rolled over before the pattern is drawn. The pattern and flask equipment for this machine is much less expensive than for the stripping-plate machine. For this reason, it appeals to the foundryman for use on those jobs that have a limited run. It is particularly advantageous in molding any job, as for example a grate bar, that has deep pockets of hanging sand where parts of the sand are nearly cut off.

The illustration on page 372 shows a plain, roll-over, draw machine and the one on page 373 a plain, roll-over, draw machine such as is used in a core room. As this machine is designed for the mold to be rolled over by hand, the size of flask is limited to what two men can roll over with the aid of the strong, counterbalancing springs with which the machine is equipped. After the mold has been rammed by hand, the bottom board is put on, and the board and mold locked securely to the pattern plate by means of a clamping rod pivoted on the same center as the pattern plate. The mold is then rolled

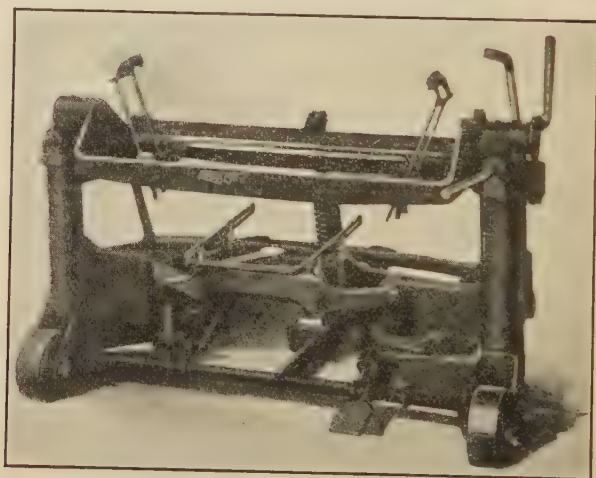


FIG. 106.—Plain roll-over straight draw machine.

over depositing the mold on an adjustable table. This table compensates for all inequalities in the bottom boards or flasks, and allows the mold to remain perfectly level when the clamping rod is released. After the clamping rod is released, the mold is lowered away from the pattern by means of a foot or hand lever, the pattern is released and allowed to swing back, and the mold is ready to be placed on the floor.

In the illustration above is shown another type of roll-over draw machine. It is built along quite different lines although it performs the same operations. It accomplishes the roll over of the mold with very little effort because the table is made to roll on its own center of gravity, and the weight of

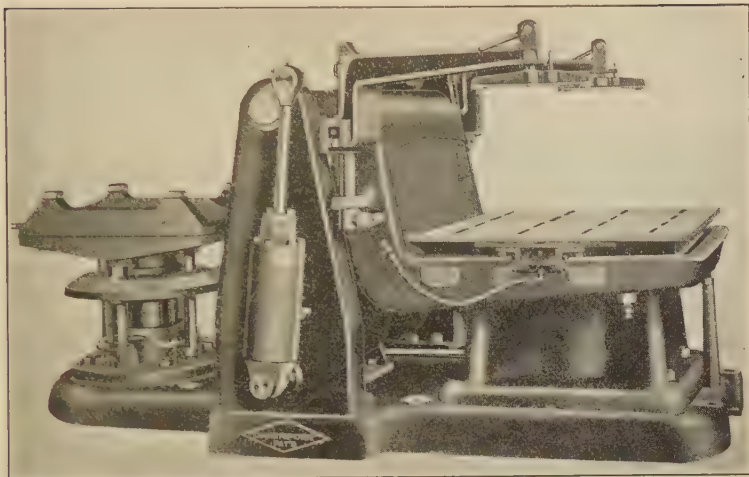


FIG. 107.—Power roll-over, power draw machine showing clamps.
(Courtesy of International Molding Machine Company.)



FIG. 108.—Jar ramming, power turnover, power draw molding machine.
(Courtesy of International Molding Machine Company.)

the mold being above the center helps to carry it over. All operations are carried on from the front of the machine. It has a very wide use in core rooms as have all the roll-over machines. The making of cores is so greatly simplified by

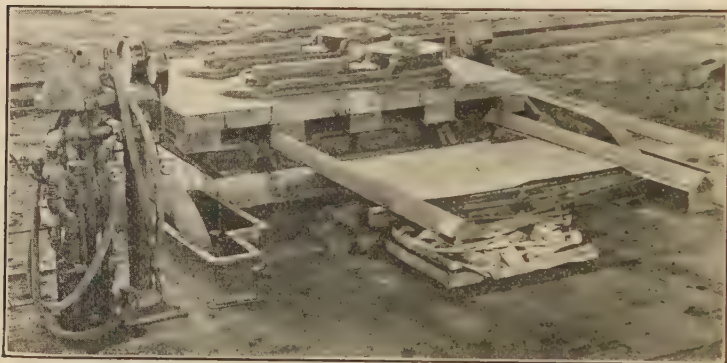


Fig. 109.—Power jolt machine with power roll-over and pattern drawing attachment. (Courtesy of Herman Pneumatic Machine Company.)

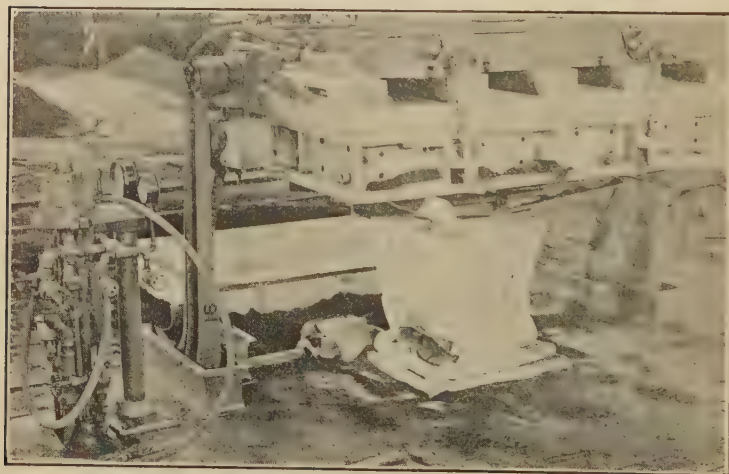


Fig. 110.—Drag roll-over pattern ready to be drawn.

using the roll-over machines that they are used as extensively in core making as in molding.

The hand roll-over machine gave such satisfactory results that a machine capable of handling much larger classes of work was soon demanded by foundrymen. This led to the

development of the power roll over. The power roll over operates along the same general lines as the hand roll over except that it is built for larger work and the rolling operation is performed by power.

The first illustration on page 376 (Fig. 109) shows a power roll-over, power draw machine. Air power is used to roll the mold over and the pattern is drawn by power. This enables much larger castings to be made than could be handled on the hand-operated machine and with less manual labor.

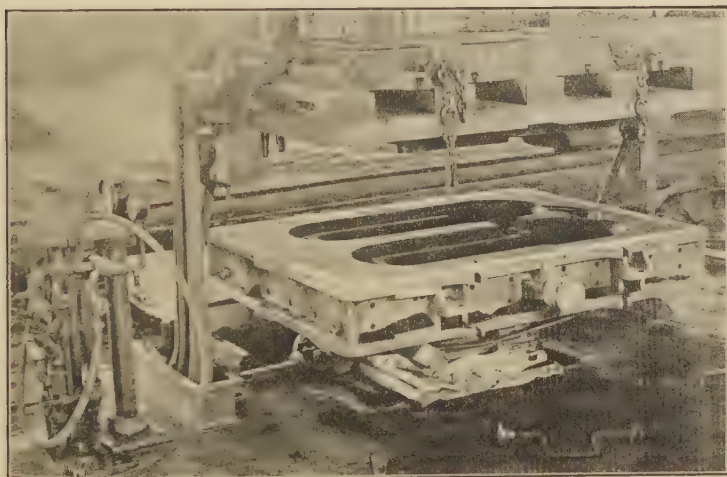


FIG. 111.—Drag lowered away from pattern. (*Courtesy of Herman Pneumatic Machine Company.*)

These machines perform both major operations of ramming the sand and drawing the pattern and also the minor ones of rolling over and clamping the board and flask.

Flask Equipment.—One of the greatest points in favor of roll-over machines of all classes is the economy of flask equipment. Due to the fact that the pattern is drawn after the flask has been rolled over, no bars are necessary in the drags. This makes wood flasks available for this class of work, as well as the usual iron flask. If iron flasks are used, they are much cheaper to construct than where the bars must conform to the pattern as in a stripping-plate job. In a large portion of side-floor work, all or nearly all of the pattern is in the drag

flask and the expense of flasks for these machines can be met by a much shorter run than on a stripping-plate job. The flasks, even though built of wood, must be made interchangeable to fit the pins in the pattern boards.

Pattern Equipment.—Patterns and pattern plates may be made of either wood or iron as the nature of the job may require. The regular wooden hand patterns may be used, whenever they are split patterns, by simply mounting them on boards and making a good joint next to the board. A leather fillet shellacked and pressed into the joint will insure a good draw without breaking the sand.

The small expense of getting patterns and flasks ready for the roll-over machines makes them especially useful and valuable to jobbing foundries.

In the jar-ram, power-roll-over and pattern-drawing machines, the only work left to be done by the operator is shoveling the sand and operating the machine. Unskilled labor is equally as proficient for these duties as the highly skilled molder.

It is always best to make a wood, lead, or other metal gate and pin it to the board to insure proper gating and save the time consumed in cutting the gate. A good smooth gate stick, reaching just to within $\frac{1}{2}$ in. of the top of the cope flask should also be provided. This will save time and take the pouring of the mold out of the realm of uncertainty.

Multiple Type Molding Machines.—During the past 20 years, multiple type molding machines have been used with varying success. For certain kinds of castings where slight variation is permitted, the multiple type is successful. Piston rings are made in this manner. The future of the multiple type molding machine is one of the points of interest to foundrymen. Some advantages are as follows: (a) molds are stacked, allowing a number to be poured at one time; (b) sand is saved; (c) floor space is saved; (d) less flask equipment is used.

Topical Questions

1. Name the several important operations in the making of a mold.
2. What item is usually first considered when putting a job on a hand roll-over rather than on a squeezer?

3. If a job had a long run and yet it was profitable to make the drag on a roll-over, on what type machine would you make the cope and why?
4. What are several advantages of a plain, roll-over, draw machine over the hand method of molding?
5. What type of cores can be made on a roll-over draw machine?
6. Give three reasons why the jolt-roll-over, draw machine is specially adapted to large work.
7. What arrangement is provided on the roll-over draw machine for leveling the mold?

Reading Reference

STOUGHTON, BRADLEY, "Metallurgy of Iron and Steel," 2d Ed., pp. 236-247.

CHAPTER LXXI

LONG-LIFE MOLDS

During the 1923 American Foundrymen's Association Convention, Dr. Richard Moldenke presented a paper entitled, "A New Long-Life Mold Development." The historical background and difficulties at that time in the use of permanent or long-life molds were presented:

The foundryman has always felt that the destruction of the mold every time a casting is poured is an inefficient procedure. Indeed, the making of molds which could be used over and over again dates back to the bronze age, when implements of warfare and domesticity were made in stone molds the two parts of which were suitably hollowed out, clamped together and poured much as our present brass ingots. These stone molds are in reality the first "long-life" molds on record. In the development of the iron industry, with molten metal at first only as an undesirable occurrence in the operation of the small blast furnaces used, the open-sand mold was the only practical means of caring for the intermittent supply of metal. As time went by, however, and the iron foundry became stabilized, the desire to construct molds which would last for more than one filling without damage asserted itself again and as early as the opening of the last century we have English patent records bearing upon the subject.

While the iron mold—or as we know it under the title of "permanent mold"—has been known and used for perhaps a century and a half, and is today attracting world-wide attention in connection with the centrifugal casting process, the method in its simpler forms has never found a solid footing in the foundry industry, the fundamental reason being that the molten metal when poured into an iron or steel mold is subjected to entirely different influences than is the case with the ordinary sand mold. The rate of cooling is much faster, with consequent more sharply defined crystallization effects and production of very fine grain structure if not actual chilling of the metal to whiteness. Even where the attempt is made to approximate the rate of cooling as in the sand mold, by

suitably preheating the iron mold, this either falls short of the desired situation if the mold is to last, or when preheated sufficiently pouring must be done at longer intervals unless the life of the mold is to be sacrificed. The consequence has been that while good castings have been made with all the permanent mold processes brought out, the irregularity of product unless corrected by careful and costly annealing has militated against their commercial success.

Following this introduction, Dr. Moldenke stated three conditions which he believed should be considered in the development of long-life molds:

1. The mold surface must be of a highly refractory character so that the least possible heat may be transmitted inward to affect the form of the mold as well as seriously limit the rate of pouring iron for castings into it . . .

2. The nature of the mold must be such that no gases are formed during contact with the molten metal, until this has set . . .

3. The mold surfaces must be sufficiently strong to resist the cutting action of the molten metal, and be impervious to the entrance of fine filaments of iron which on removal of the casting would take some of the material with it. Further, the mold surfaces must not spall off . . .

The term "long-life" is used advisedly as against "permanent" for in the latter the supposition is that no repairs are made on the metal mold; whereas in the former, repairs are possible and are carried out until they no longer pay.

The author of this paper then describes a patented process for the making of long-life molds, and evaluates it saying that since some of the molds had

. . . already had 10,000 castings made in them and by reason of close inspection of and attention to the refractory facing material of the molds not one of them has yet had to be discarded, the writer feels that here is truly a new development in making long-life molds.

This discussion of long-life molds accompanied by a number of views showing the molds and mechanical devices for production purposes was printed in the Transactions of the American Foundrymen's Association, Vol. XXXI, 1924. It closes with the statement that the process is still in its infancy, for while attention has so far been given to quantity pro-

duction of light castings, larger work will be undertaken as the process is adapted to their requirements.

As an illustration of the rapidity with which progress is being made in the foundry industry, we may look back to the opinion on long-life molds expressed by Dr. Moldenke six years previous to the presentation of the paper just referred to and then look forward five years to a description written in 1928 for *The Iron Age* of the results achieved by the improved long-life mold.

In 1917, Dr. Moldenke wrote in the book, "Principles of Iron Founding" (p. 31):

As to the permanent mold, of which one hears so much in the foundry but which seems so elusive as yet, the day will unquestionably come when much of the repetition work which lends itself to this line of endeavor will be made in at least "long-life" molds, if not the so-called permanent (iron) ones.

In *The Iron Age* of May 3, 1928, is an article by Harry Kimber of the Holley Carburetor Company in which is described the progress of this company in developing the long-life mold:

The management decided that the permanent or long-life mold was a possible way out of this uncomfortable situation (regarding automobile carburetors) and experimental work began in 1922. They knew that an unprotected cast-iron mold was impractical; so an intensive search was soon under way to find a suitable protection for such a mold. Many coatings were tried before the satisfactory combination was discovered. This refractory coating, which is cheap, easy to prepare, easy to apply, and permanent, made the Holley long-life mold a definite success. Production was begun at once on the above mentioned carburetor casting, and when it was finally discontinued over 7,000,000 castings had been produced in Holley molds in a little over 2 years.

Henry Ford became interested in this mold and the automatic machine which was developed to carry it. The Ford Motor Co. now has nine of these machines in its foundry, producing hundreds of thousands of small gray-iron castings for the Model A car and pistons for the Fordson tractor. Thousands of cast-iron pistons were also made for the Model T car by this process. The carburetor body for the Model A is now being produced in large quantities on these machines in the Holley Carburetor Co.'s new sandless foundry.

The production possibilities of this machine were soon recognized by manufacturers and foundrymen both in this country and in Europe, and many of them now are using the machines in their own foundries. The Delco Remy Corporation, a subsidiary of the General Motors Corporation, is completing plans for the erection of a new 100-ton sandless foundry at Anderson, Ind.

Castings ranging from 6 oz. to 25 lb., thick and thin, and with and without cores, are now being produced in large quantities in the Holley molding machines . . .

A number of machines have been designed and built during the last five years, and with each succeeding design, an improvement has been made. Water and oil as cooling mediums were experimented with, but air was finally selected because of its safety, efficiency, and the simplicity of its application.

The rotating 12-headed machine has recently been redesigned and is now under construction. It is a decided improvement over the machines now in service.

The molds now in use are cast in dry sand molds with the same iron as that used for the castings. These molds have a multiplicity of pins cast on the back, and, when mounted on the machine, low-pressure air is passed over these pins at the rate of 100 to 200 cu. ft. per minute. The volume of air is regulated so that the temperature of the mold remains within a certain range. The blower is overhead along the wall of the building, and is arranged so that the air blows on the molds in cold weather, and is drawn over them and exhausted out of the building in hot weather. This takes care of the heating and ventilating of the foundry very satisfactorily.

A series of tests with molds cast of various alloy irons is now in progress but will not be completed for some time. However, with proper control of the cooling system, ordinary gray-iron molds have an average life of 15,000 castings on the automatic machines.

The molds are cast to size and require very little machining. After the machine work is completed, they are heated to about 500° F., and the refractory coating is applied to the face of the mold with a soft brush. As previously stated, this coating is permanent, but it does wear off in places where there is only a slight draft and in the sprue. These spots are touched up at the end of the day's run while the molds are still hot. Care of the molds is a most important, though simple, task.

At the beginning of the day the molds are heated with gas to a temperature of 500° F. before the first castings are poured. From then on the pouring is continuous throughout the day, except when the crew is out to lunch.

Topical Questions

1. Why are castings made on long-life molds reheated?
2. Why is it necessary to heat long-life molds previous to pouring the first mold in a run?
3. What is meant by the "entrance of fine filaments of iron which on removal of the casting would take some of the mold material with it?" How does this apply to green sand molding?
4. Why is a refractory lining necessary to the success of long-life molds?
5. Why is air considered a suitable cooling agent in the use of long-life molds?

CHAPTER LXXII

SANDSLINGER MOLDING MACHINES

One evidence of the rapid advance being made in the foundry industry is the use of the sandslinger. As recently as 1920, Andrew McWilliam and Percy Longmuir, in the third edition of their book, "General Foundry Practice," said:

The term "machine molding" should be interpreted with tolerance, for comparatively few molding machines are, in the full sense of the word, mechanical.

The authors referred to the fact that in most cases some handwork was necessary to complete the mold, hence, the process could not be termed strictly mechanical. This is true only in the sense that some handwork is necessary in all machine operation. Some one must do something in connection with even the most "human" machine.

Since molding machines were first used, foundrymen have looked forward to the time when a general molding machine would be a reality. While the sandslinger is a long step in this direction, some foundrymen are still looking for the general molding machine. In the words of the authors quoted above:

From a foundry point of view, no one type of machine is, or can be, universal; each machine must be regarded as a tool specially adapted to produce a particular class of work in which alone its full possibilities will be realized. The variety of designs actually in use, each one giving satisfaction in a particular field, illustrates this.

Each molding machine, no matter how perfect its mechanism, requires a certain amount of skill from the operator. The statement so often made that any unskilled laborer can successfully handle a machine is by no means true. Some skill on the operator's part is essential, and a very considerable demand in this direction is made on the management, if full results are to be obtained.

It is a mistake to assume that there may come a time when skill in molding will be entirely replaced by machine operation. Skill is a result of training, whether it is demonstrated by the highly developed technique of an artist, or by extremely simple operations. There is no human activity which cannot be done a little better the second time than the first. Perhaps the improvement is slight but it is exactly this slight improvement which is needed. Even the sandslinger should require a little skill in operation, and it is suggested that this is possibly a field for advantageous investigation.

The drawing of patterns, the setting of cores, the closing of molds, and pouring, all require skill, judgment, and experience, many times of an exceedingly high degree, whether done in connection with sandslingers or any other type of molding machine.

On the other hand, the sandslinger has accomplished significant strides in the direction of simplified molding practice.

Many years ago, progressive foundries began the installation of sand conveyors, and overhead sand chutes have long been a convenience for molders whose physical labor has consequently been reduced. The sandslinger combines this arrangement with the slinging device and makes available a sand conveyor and mixer for floor work which has not usually been considered as readily adapted to the overhead sand-conveyor system.

A number of claims are advanced by sandslinger enthusiasts whose number is increasing. Among these are the following:

1. No special flask or pattern equipment is required.
2. Air equipment is not required.
3. Crane service is reduced.
4. Floor space is saved.
5. Density of molds is subject to control.
6. The life of flask and pattern equipment is increased.
7. The sandslinger is sand cutter, aerator, conveyor, riddling, and ramming device all in one.

Some of these statements might be questioned by foundrymen, but no one will question the fact that the sandslinger is a progressive foundry development. It is being adapted to

work which at first was considered impossible of sandslinger accomplishment. There will always be jobs on which other types of molding equipment are specially economical. With these facts in mind, a careful study of the sandslinger as representing one of the latest generally accepted achievements in molding machine production should be undertaken.

The impeller head, *A*, is the central unit around which all types of sandslingers are constructed. This is a mechanical device consisting of a paddle wheel which receives sand from the conveyor *B* and impells it in small handfuls into the mold

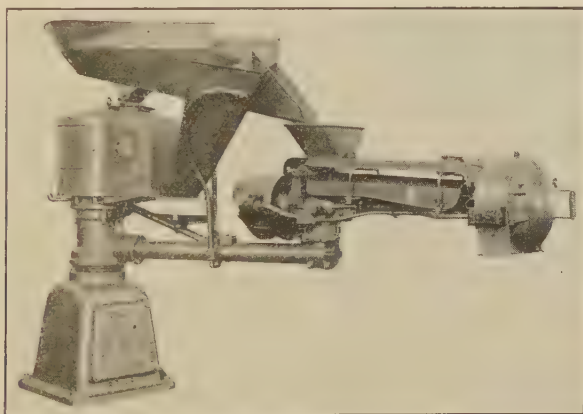


FIG. 112.—Stationary type sandslinger. (Courtesy of The Beardsley and Piper Company.)

which is placed in a convenient position beneath the impelling head. The revolutions of the paddle wheel are rapid; hence, the impelling operation has the appearance of a constant stream of sand being blown into the flask or pit rather than of thousands of small handfuls of sand being thrown to form the mold. Controls are located on the impeller heads within easy reach of the operator to facilitate quick and easy starting and stopping.

In most types of sandslingers, sand is fed by bucket elevators from sand heaps or tanks. After being conditioned, it is carried to the ramming unit. A delivery belt feeds sand out of the ramming unit hopper which is mounted on a

frame at the motor end of this unit. By means of this belt, the sand is delivered to the rapidly rotating cup-shaped tip in the impeller head, *A*, from which the sand is thrust into the mold.

Sandslingers are made in five types with a view to being applicable to different kinds of foundry work. These types are described as follows:

Type I.—The stationary type sandslinger is designed for use in production foundries having overhead sand-conveying systems used with auxiliary sand-handling equipment for supplying the sandslinger with sand. This type is usually bolted to a concrete foundation and is used in conjunction with mold conveyors.

The stationary type sandslinger with a specially designed turntable is intended for use in foundries where it is desired to serve, in a continuous manner, a multiple number of patterns. It is designed with double belt for use in production foundries having overhead sand conveying systems, in which it is necessary to use a longer ramming arm than it is possible to build with standard type machines.

Type II.—The tractor type sandslinger is designed for use on production work in foundries where the amount of floor space and head room permits such an installation. This type requires no auxiliary sand-handling equipment, but is built to travel on special tracks set into the floor between which sand is stored for conditioning, aerating, riddling, and ramming in one operation. These machines have been used on miscellaneous work with wood flasks and old style patterns. Where it is desired to use the unit on production work, however, stripping-plate machines and metal flasks are recommended. In such case, pattern machines can be mounted on wheels or skids and towed by the sandslinger to convenient ramming positions.

The tractor type with jib cranes is intended to meet the foundry condition where crane capacity is limited and where jib cranes mounted on the machine can be used to advantage. The tractor type is used on such work as tractor engines, corn harvester frames, stationary engines, soil pipe, and miscellaneous parts of varying shapes and sizes.

Type III.—The portable type sandslinger is designed to meet conditions in smaller jobbing shops. It is moved about the shop as desired with a crane of 5 tons or more capacity. Another variety of the portable type may be pushed about the shop on wheels. It is used where a crane is not available. Another kind of portable machine with tank feeder is designed for the shop where the bulk of the work ranges from small to medium size, and which has an occasional large job.

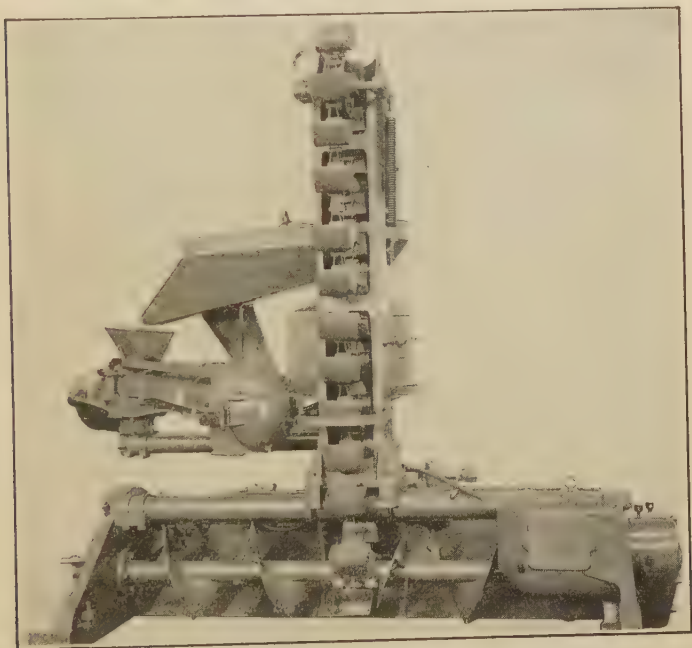


FIG. 113.—Tractor type sandslinger. (Courtesy of The Beardsley and Piper Company.)

Type IV.—The motive type sandslinger is best adapted to medium and large sized work and work of miscellaneous character. It is claimed for this type that it rams pits of any width within reach of its arm and up to 10 ft. in depth. It handles dry or green sand, and it is said to prepare molds for large castings, for example, castings for pumping engines, compressors, large sizes of pipes and fittings, planer beds, and miscellaneous machine tools as well as for medium and small sized steel castings.

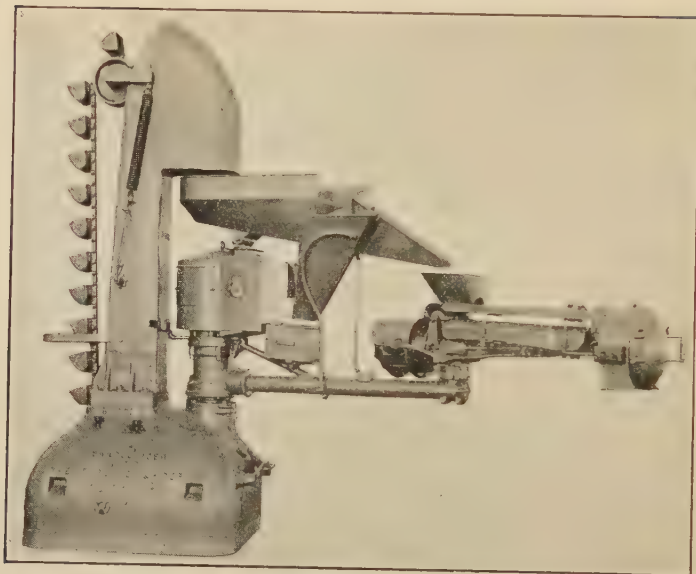


FIG. 114.—Portable type sandslinger. (*Courtesy of The Beardsley and Piper Company.*)

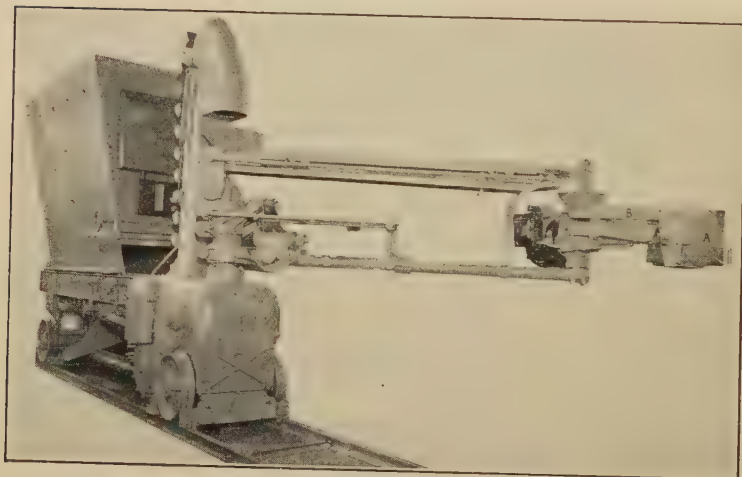


FIG. 115.—Motive type sandslinger.

Type V.—The locomotive type sandslinger is a complete sand conditioning, sand handling, and ramming unit, and travels under its own power in either direction on 80-lb. rails. The rails are set wider apart than is the case with the tractor type. It is the general practice with this type to use the space between the rails for shakeouts and sand storage. After the desired percentage of moisture has been added to the heap, the machine travels into it under its own power, cutting,

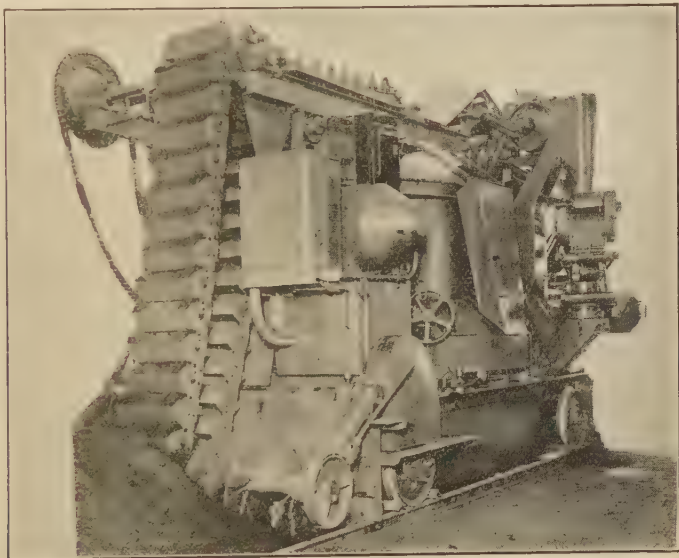


FIG. 116.—Locomotive type sandslinger. (Courtesy of The Beardsley and Piper Company.)

riddling and depositing the sand back between the rails at a rate of approximately $3\frac{1}{2}$ tons of sand per minute. It is designed for molds of large and miscellaneous character: large sized pipes, valves and fittings, superheater castings, smoke boxes, fronts, dumpers, grate frames, pumps, and miscellaneous work common to large jobbing and production foundries.

Topical Questions

1. What mechanical principle is involved in slinging sand from the sandslinger into a mold? Explain.

2. How does the sandslinger aerate sand?
3. What should the sandslinger operator do to assure desired permeability of sand in the mold?
4. For what type of foundry work is the sandslinger best adapted? Why?
5. What types of foundry equipment aim to reduce the amount of shoveling of sand?
6. Describe conditions under which each of the five types of sand-slingers may be economically used.
7. Under what conditions would you advise against the use of any certain type of sandslinger?
8. What other types of molding machines may be used in conjunction with a sandslinger?
9. How are types of other foundry machines used in connection with the sandslinger?
10. Why is skill a necessary consideration in every molding operation regardless of the type of equipment?
11. Describe the various types of skilled work some of which are absolutely necessary in connection with the use of the sandslinger.

Reading References

1. McWILLIAM, ANDREW, and LONGMUIR, PERCY, "General Foundry Practice," 3d Ed., revised, "Machine Molding," pp. 131-144.
2. SKLOVSKY, MAX, Moline, Ill., "A Method of Treating and Handling Molding Sand," with discussions by others, *Transactions of American Foundrymen's Association*, Vol. XXXIII, 1926, pp. 708-720.

CHAPTER LXXIII

MISCELLANEOUS MOLDING AND CORE-ROOM EQUIPMENT

COMPRESSED-AIR, SAND-RAMMING MACHINES CORE-MAKING MACHINES AND CORE OVENS

A compressed-air, sand-blowing machine was exhibited at the 1928 convention of the American Foundrymen's Association. While many foundrymen are of an opinion that sand blowing as a method of molding is yet an experiment, it is thought that the possibilities in the method warrant a brief description of the sand blowing machine. Professor William H. Dosey, Carnegie Institute of Technology, describes the equipment as follows:

This compressed-air, sand-blowing molding machine rams molds by blowing a continuous stream of molding sand into the flask. This process results in a very uniform compression of the sand. By varying the working pressure and the ratio between sand and air quantities, the operator is enabled to control the degree of hardness to which certain molds or parts of molds should be rammed. This control of pressure and ratio also makes it possible to use molding sands of different physical characteristics. The nozzle through which sand is blown into the flask permits of being held at any angle, thus insuring uniform density on steep walls and under cross pieces as far as these are conveniently designed.

This machine consists of a pressure device of 2 cu. yd. capacity and a storage vessel or hopper above, which may be kept closed by a stop valve. The pressure device contains a distributing plate with adjustable stripper which first is slowly rotated by a motor combined with the machine. The stripper takes the adjustable quantity of sand off the distributing plate and brings it up into an air jet discharged from beneath which in turn carries the sand into the flexible tube connected with the blowing nozzle. Sand may be delivered to the hopper by an elevator, overhead feed, grab buckets, or any other suitable means, according to the local conditions.

The amount of sand delivered into the flask by this machine is from 4 to 12 cu. ft. per minute, and the quantity of air required (referring to the volume drawn in) is about 175 to 280 cu. ft., according to the density and quantity of the sand desired. The necessary air pressure varies between 21 and 35 lb. per square inch. The average length of the flexible tube is 26 ft., but this may be increased up to 65 ft., thereby very much extending the radius of action.

Cores are made by hand and by machinery. The machines range from simple devices used in making small special cores

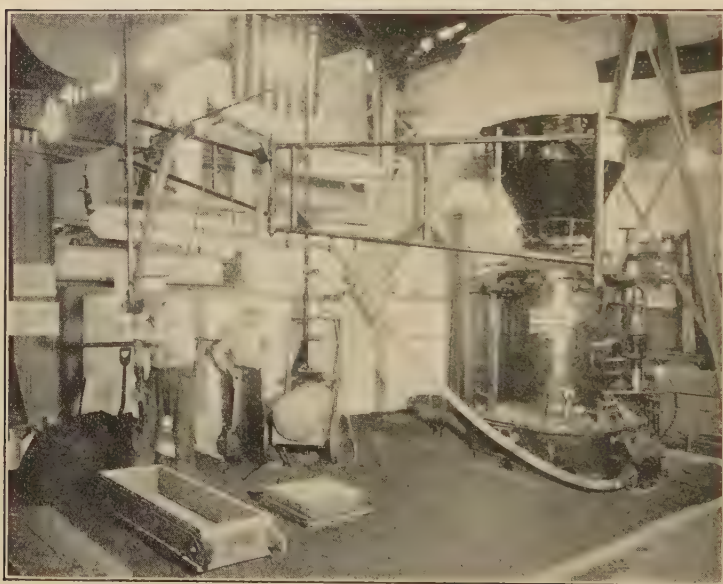


FIG. 117.—Sand blowing machine. (Courtesy of Albert T. Otto and Sons.)

to regulation core molding machines duplicating the operations which have been described in the preceding chapters.

The core-blowing machine is employed for core making by most of the foundries engaged in production work. Most small core work can be made to advantage on the machine, including cores for plumbing goods, pipe fittings, stove burners, valves, vacuum cleaners, and various automobile castings.

The core is made by forcing the sand into the core box by compressed air, the operation of filling the box being accomplished in about five seconds regardless of the size and shape of the box. Simple sharp sand cores can be made with

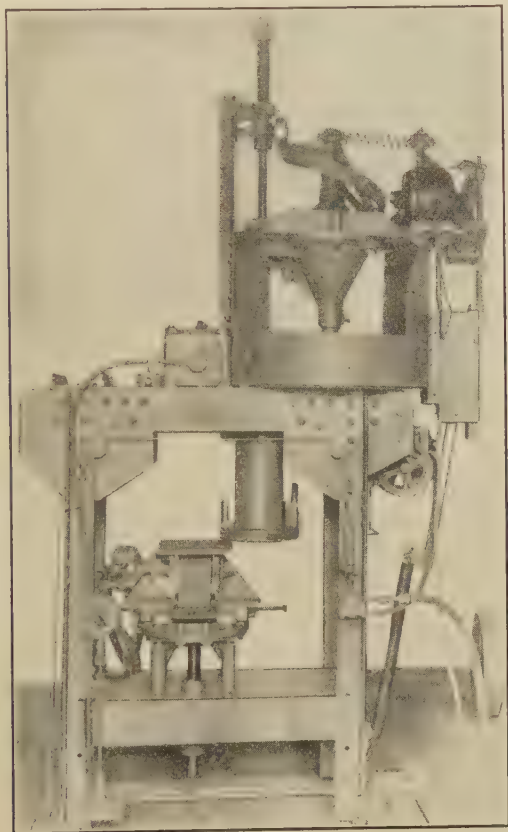


FIG. 118.—Core blowing machine. (*Courtesy of Wm. Demmler and Company.*)

70 lb. air pressure, whereas intricate cores and standing cores of loam-sand mixtures require pressures of from 100 to 125 lb.

The machine is controlled by light pressure upon a treadle, the air automatically performing the several operations



FIG. 119.—Hand ramming, hand turnover, hand draw, molding machine used in a core room in making dry sand cores. (Courtesy of International Molding Machine Company.)

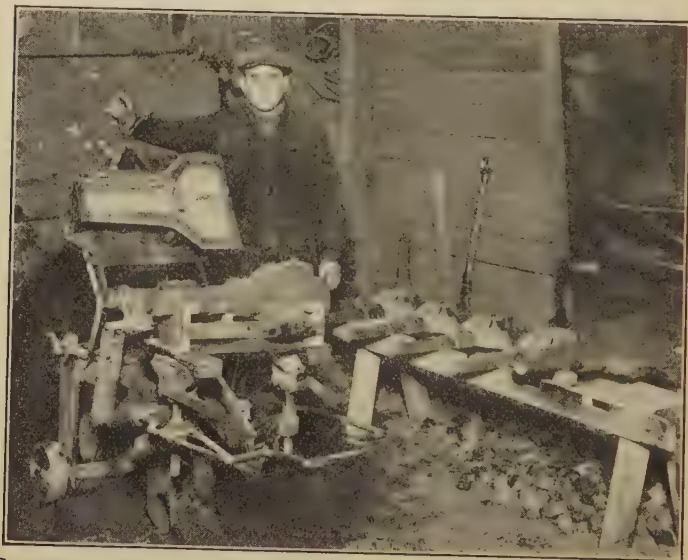


FIG. 120.—Illustrating practice in many automobile shops combining dry and green sand cores. The green sand "halving," as it is sometimes called, is being made for the dry sand core shown with the hand ramming, hand turnover, hand draw, molding machine.

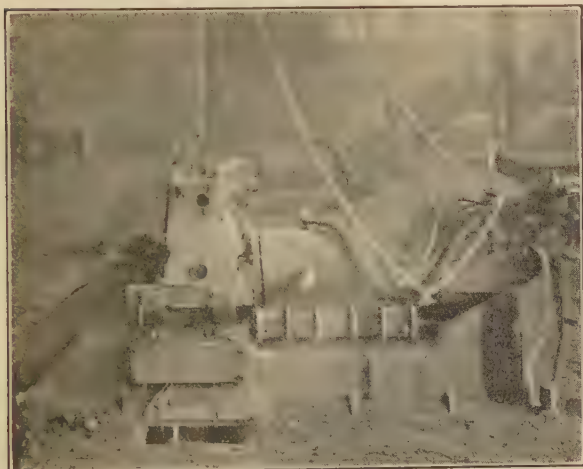


FIG. 121.—Large core knockout machine in operation. (Courtesy of The Stoney Foundry Engineering and Equipment Company.)

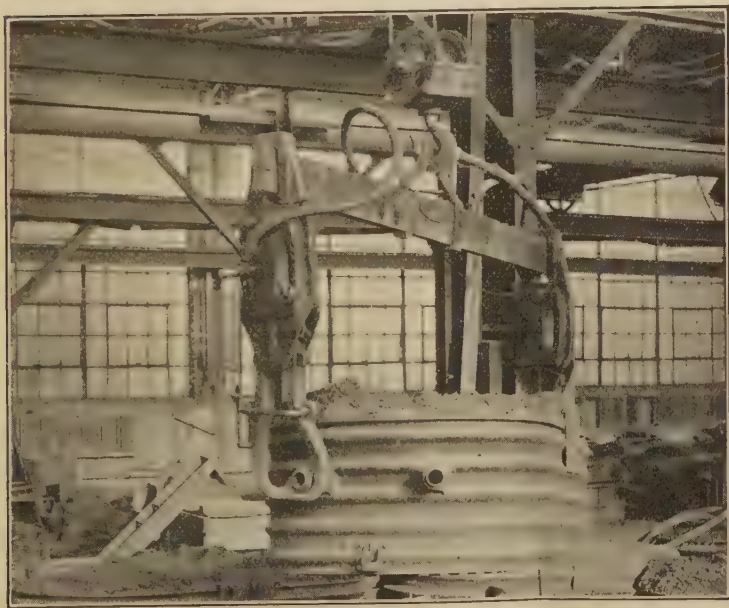


FIG. 122.—A shakeout bail for large molds. (Courtesy of The Stoney Foundry Engineering and Equipment Company.)

successively, clamping and filling the core box, and thus releasing it after the core is made. It has a capacity of about 200 cores per hour, though much greater production is often obtained on cores which are easily removed from the core box.

Cores may be made from sharp-sand or loam-sand mixtures, using any binder which may be used for handmade cores, except that too much flour should not be used. Too much flour prevents the sand from flowing freely.

Sand mixtures containing a large proportion of loam for standing cores do not flow well in a core machine without some means of feeding the sand. A motor driven device which operates automatically is provided for this purpose. The sand magazine returning to filling position sets it in motion; the sand is pushed over the sand magazine by a revolving sweep and forced down into the magazine by a plunger. This insures a positive flow of sand to the machine.

Cores made on the machine are more uniform than hand rammed cores and are porous. They are ideal cores for casting, and users of the machines appreciate the saving effected in reducing casting losses.

Core knockout machinery is essential in many foundries. The first illustration on page 397 shows a large core knockout machine in operation. The second illustration shows a shake-out bail for large molds.

Topical Questions

1. Would the sand-blowing machine ram just as hard through a flexible tube 48 ft. long as it would through a flexible tube 28 ft. long, using the same air pressure in both cases? Explain.
2. What part or parts of the sand-blowing machine would probably be subjected to the hardest wear? Explain.
3. What are some important differences between the methods of operation of the compressed-air, sand-ramming machine and the core-blowing machine?
4. For what type of work is the core-blowing machine best adapted?
5. Give examples of cores best adapted to a hand-ramming, hand-turnover, hand-draw machine.
6. Give some important reasons why cores should be knocked out of some castings immediately after these castings are poured.
7. Describe the operation of a knockout bail.

References

1. CARMAN, EDWIN S., "Foundry Moulding Machines and Pattern Equipment," Chap. XIII. (Core making.)
2. McWILLIAM, ANDREW, and PERCY LONGMUIR, "General Foundry Practice," Chap. IX. (Core making.)
3. MOLDENKE, RICHARD, "Principles of Iron Founding," pp. 300-316. (Core making).
4. WENDT, R. E., "Foundry Work," pp. 132-139. (Core making.)
5. *Iron Trade Review*. (Sand blowing) June 21, 1928.

GLOSSARY OF FOUNDRY TERMS

The definitions marked * have been reprinted from the more extensive Glossary, pp. 459-463, Moldenke's "Principles of Iron Founding." The words defined here are foundry terms used either in this text or in the other sources of information to which references have been made.

Air-dried.—The surface drying of cores left in the open air before being baked in an oven. Also applies to molds which air-dry when left open, thus causing crumbling or crushing when metal is poured.

Baked Core.—A dry-sand core which has been subjected to heat. Green sand cores are used without baking.

Bars.—Ribs of metal placed across the cope portion of a flask. Sometimes called "cleats."

***Bath.**—Molten metal held in hearth of furnace during melting process.

***Bed or Bed Charge.**—Initial charge of fuel in cupola upon which the melting is carried on.

Binder.—Material used to hold sand together.

Blackening.—A thin facing of carbonaceous materials, such as graphite or powdered charcoal, used to finish mold surfaces and protect the sand from the hot metal.

Black Lead.—Graphite, a form of carbon which is soft and greasy.

Blast.—Air driven into the cupola or furnace for the combustion of fuel.

Blow-holes.—Holes in castings due to air or other gases trapped in the metal.

***Bod.**—A cone-shaped lump of clay attached to the end of an iron or wooden "bod-stick" used to close the tap-hole of the cupola.

***Bottom (Sand).**—The layer of sand with clay rammed upon the bottom doors of the cupola to form the sloping hearth or crucible bottom.

Bottom Board.—A board of wood or metal on which a mold rests.

***Breast.**—Part of cupola lining connecting spout with bottom and made up with tap hole for every heat.

Bull Ladle.—A ladle for carrying molten metal having a shank and two handles. Two or more men are required for carrying it.

Burnt Sand.—Sand in which the binder has been burned by contact with molten metal.

Cementite.—The constituent of commercial iron which is a chemical combination of iron and carbon (Fe_3C).

Chaplet.—A metal support used to hold a core in position. Not used when a pattern has a core print which serves the same purpose.

***Charge.**—A given weight of metal or fuel introduced into the cupola or furnace.

***Charging Door.**—Opening in cupola or furnace through which the charges are introduced.

Cheek.—The middle part of a flask or mold that has more than two parts. A two-part mold has only a cope and drag or nowel.

***Chill.**—A properly shaped casting, forming part or the entire interior mold surface, intended to withdraw heat from the molten metal so rapidly that it solidifies faster at that point and becomes sound. Also, the hard white-iron portion of the casting resulting from the contact of the molten metal (of proper composition) with the iron "chill" (or chiller) above mentioned.

***Chipping-out.**—The process of removing slag and refuse attached to the lining of the cupola or furnace after a heat has been run.

***Clay-wash.**—A thin emulsion of clay and water.

Cold shots.—Small particles of metal formed by the splashing of the molten metal in the mold. They harden quickly and adhere to the casting without amalgamating with the other metal.

***Cold-shut.**—An imperfect junction line between two flows of metal in a mold.

Contraction.—Decrease in volume during cooling after casting. Shrinkage is applied in the foundry to the decrease in volume during the change of metal from the liquid to the solid stage and contraction immediately succeeds it. The result of shrinkage is observed in the interior of a casting as very great porosity or as open spaces, while the result of contraction is observed as the difference in size of pattern and of the cold casting.

***Cope.**—The upper part of a mold.

***Core.**—A body of green or dry sand placed in the mold to form a corresponding cavity in the casting.

Core Box.—A mold in which a core is formed. Not all cores are formed in boxes.

Core Compound.—A commercial mixture to supply the binding material needed in making cores.

Core Irons.—Bars of iron embedded in a core to strengthen it.

Core Print.—A projection on a pattern which forms in the sand of the mold an impression into which the core is laid.

Core Sand.—Sand free from clay, of nearly pure silica; any sharp sea sand.

Core Wash.—A commercial blackening mixture with which cores are painted.

Cupola.—A variety of the shaft furnace.

Cutting Over.—Shoveling or turning over of sand to obtain uniform mixture and temper.

Daubing, Daubing Up.—The process of applying a mixture of clay and sand to cupola or ladle linings.

Draft.—The slight taper on a pattern that makes easier its withdrawal from the sand.

Drag.—The lower part of the mold when it is in position for pouring.

Drawing.—Removing the pattern from the mold.

Draw Plate.—A plate put into a pattern or attached to a pattern to facilitate drawing.

Drop, Drop-out.—The falling of sand from an overhanging surface in the mold.

Dry Sand.—Sand dried in an oven.

Dull Iron.—Iron below the temperature required for successful pouring.

Dump (cupola).—The fuel bed and slag falling out of the cupola when the bottom is dropped after the heat has been run.

Eutectic (of molten metal).—The portion of a mass of molten metal which solidifies last. As the mass cools, various elements and compounds solidify and segregate out at their respective setting points. The portion that remains, the eutectic, solidifies at a temperature determined by its composition and other factors.

Facing, Facing Material.—Material used on the surface of a mold to protect the sand from the heat of the molten metal.

Feeder Head, Shrinkage Head.—A body of molten metal in a riser or other opening above a mold from which metal is supplied to the mold as shrinkage takes place.

Feeding.—Pouring additional molten metal into a freshly poured mold to care for volume shrinkage while the casting is setting.

Fin.—A thin projection on the casting due to an imperfect joint in the mold.

***Fire-brick.**—Brick made of highly refractory clays.

Fire-sand.—A highly refractory sand.

Flask.—A container of wood or iron in which a mold is made.

***Flux.**—Basic material added to the cupola charges to unite with sand, ash, and dirt during the melting, to form a slag.

Follow Board.—A board which conforms to the form of the pattern and defines the parting surface of the drag.

Founding.—The making of metal castings, or the casting of metals in molds.

Gaggers.—Supports of metal, usually iron, used to reinforce the sand in the cope. They are shaped like the letter L.

Gate.—The end of the runner where the molten metal enters the mold. Or the opening cut in the sand of the cope through which the molten metal is poured into the mold.

***Gray Iron.**—A cast iron the combined carbon of which is under two-fifths of the total carbon contained.

***Green Sand.**—Molding sand tempered up with water.

Head.—An opening in the sand above and connected with the mold. Also the pressure exerted by a fluid as of a head of steam or of molten metal.

Heap Sand.—Green sand from the foundry floor.

Hearth.—The floor of a furnace.

Heat.—A stated tonnage of metal obtained from a period of continuous melting in cupola or furnace. Or the melting period required to handle this tonnage.

Jar Ramming, Jolt Ramming.—The packing of the sand in the mold by the raising and dropping upon a table of the sand, pattern and flask, the sand itself being the ramming medium.

Jolt squeezers, jarring machines, and jolt rammers are molding machines using the principle of jar ramming.

Loam.—A mixture of sand, clay, and some venting material which gives a firm, hard, and open-grained body when dry.

Loam Molds.—Molds built up of bricks, plates, and other sections covered with loam to give the form of the castings desired.

***Machinability.**—The property of permitting tooling or finishing by machinery.

Malleable Cast Iron.—White cast iron of proper composition which has been rendered malleable by annealing.

Match Plate.—A plate to which the pattern is attached at the parting line.

Melting Loss.—Loss of metal in the charge during the operation of melting.

Melting Rate.—The tonnage of metal melted per hour.

Melting Ratio.—The proportion of the weight of metal to the weight of fuel in cupola melting.

Melting Zone.—The portion of the cupola above the tuyeres in which the metal melts.

Mending Up.—Repairing broken surfaces in the mold.

***Mold.**—A body of molding sand or other heat resistant material containing a cavity which, when filled with molten metal, yields a casting of the desired shape.

Mold Board.—Board upon which the pattern is placed to make the mold.

Molding Machine.—A machine, operated either by hand or power, for making molds.

***Molding Sand.**—Sand containing sufficient refractory clay substance to bond strongly without destroying the permeability to air and gasses when rammed to the degree required.

Nowel.—Commonly called the drag. The lower portion of a mold when it is in position to cast.

Old Sand.—Sand in which castings have been poured.

Parting.—The joint or plane of separation in molds having more than one section.

***Parting Sand.**—A fine, bondless sand dusted on the joint of a mold to prevent the cope and drag from adhering to each other.

Peeling.—The ready dropping away of sand from a casting when cool.

Peen.—The flat-pointed end of a rammer used in ramming sand into a mold.

Pig Bed.—Small excavations or regularly made open-sand molds in the floor of the foundry, to hold the excess iron in the heat.

Pouring.—Filling the molds with molten metal.

***Pouring Basin.**—A basin in the cope to hold molten metal prior to its entrance into the gate.

Prop.—An iron post used to support the bottom doors of the cupola.

Pumping.—The act of churning molten metal in the risers of a mold.

Ramming.—The operation of packing sand around a pattern in a flask to form a mold.

Rammer.—A tool used in packing sand around a pattern in a flask.

Rapping.—Knocking or jarring the pattern to loosen it from the sand in the mold before withdrawing the pattern.

Rapping Plate.—A metal plate attached to a pattern to prevent injury to the pattern and assist in loosening it from the sand.

Refractory.—The quality of resisting heat.

Riddle.—A sieve for removing the coarse material in the sifting of sand.

Riser.—An enlarged gate which acts as a feeder for the casting.

Rolling Over.—The operation of reversing the position of a flask in which the drag part of the pattern has been rammed with the parting surface downward.

Roll-over Machine.—A molding machine by which the flask is rolled over before the pattern is drawn from the mold.

Runner.—An enlarged basin, or channel, through which molten metal is carried to the gates.

Run-out.—A break in a mold resulting in the metal flowing out.

Scabbed Castings.—Castings having rough surfaces.

Scrap (metal).—Metal to be remelted, includes sprues, gates, risers, defective castings, and scrapped machinery.

Sea Coal.—Finely ground soft coal, mixed with molding sand.

Shrinkage.—Technical term used by foundrymen to denote change in size as the metal passes from the fluid to the solid state in the mold.

Shrink-hole.—Opening in the surface or the interior of a casting due to insufficient volume of metal in cooling.

Skim-gate.—Any arrangement that will retard the flow of skim or slag into a casting.

Skimming.—Holding back from a casting the dirt, slag, or skim in the molten metal.

Skin-drying.—The drying of the surface of the mold by direct application of heat.

Slag.—The molten substances other than the metal which separate out from molten metal when allowed to stand.

Slick, Slicker, Smoother.—A tool used for smoothing the surfaces of a mold.

Snap Flask.—A flask used for small work, differing from the ordinary flask in that it has hinges and latches or some other device so that it can be opened or held together as desired.

Softeners.—Metals, alloys, or other materials added to the charge for the purpose of reducing the hardness of the castings.

Soldiers.—Thin pieces of wood used to strengthen a body of sand or to hold it in place.

Split Pattern.—A pattern made in two or more parts.

Spongy Casting.—A casting with very open grain.

Spout.—The part of the cupola or furnace which carries the metal from the tap hole to the ladles.

Sprues.—Channels from the gate into the mold. Also the metal which solidifies in the gates, risers, runners, and pouring basins of a mold.

Sprue Cutter.—A tool for cutting the sand of the mold so as to form a channel for the flow of metal.

Squeezer.—A molding machine which compresses the sand in a mold to the desired density.

Stopping-off.—Filling up or closing off a portion of a mold which is not to be cast.

Stopping Up.—The plugging with clay of the tap hole in the cupola.

Straining.—The distortion of a mold by the pressure of the molten metal. The sinking of the sand in the mold.

Stripping Plate.—The plate which holds the sand in place while the pattern is being drawn through the plate.

Stripping Plate Machine.—A molding machine having a plate on which the mold is made and by which the patterns are drawn from the mold.

Swab.—A sponge or piece of waste, hemp, or other material used in dampening sand around a pattern before withdrawing it. Sometimes used in blackening molds which might be broken by a brush.

Sweep.—A board having the profile of the desired mold, which, when revolved around a stake or spindle, produces that mold.

Sweep-work.—The making of molds with sweeps instead of patterns.

***Tap-hole.**—The opening in the cupola and furnace breast through which the molten metal is tapped.

Tempering Sand.—Dampening and cutting over or otherwise mixing sand so as to produce uniform distribution of moisture.

Trowel.—A tool used in slicking, patching, and finishing a mold.

Tucking.—Pressing sand with the fingers under flask bars, around gagers, and other places where the rammer does not give the desired density.

***Tuyere.**—An opening in the cupola through which the blast is forced.

Vent.—A small opening in a mold to facilitate the escape of gases.

Vibrator.—A device, operated by compressed air or electricity, for loosening patterns.

Weak Sand.—Sand lacking in the proper amount of clay or bond.

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INDEX

A

Abrasives in cleaning castings, 27, 40
 Acid (acids), 6
 bases and salts, 38ff.
 defined, 38
 hydrochloric, 40
 hydrofluoric 38, 40, 43ff.
 in cleaning castings, 42
 lining of electric furnace, 317
 nitric, 18, 40
 non-metal, 44
 phosphoric, 44ff.
 refractories, 214
 silica, 39, 44
 sulphuric, 6, 40ff., 58, 77, 88
 test for, 39
 Adhesion, 23ff.
 versus cohesion, 25
 Agricultural castings, 355
 scrap, 229
 Air, composition of, 18, 86
 compressed, 170
 compressors, molding machines,
 350
 used in squeezing, 350ff.
 control of amount in cupola,
 240ff.
 delivery and measurement in
 cupola, 238ff.
 furnace, 235
 in blast furnace, 216
 pressure, 238
 tools, 173ff.
 weight of air at different tem-
 peratures and pressures,
 239ff., table, X
 used in cupola, 86
 Alkalis (see *Bases*).

Alloy (alloys), 4, 14ff.
 melting point of, 75
 metallic, defined, 16
 Alumina, a basic substance, 39
 in sands, 271
 Aluminum, 9, 13, 194, 209
 latent heat of fusion, 71
 melting of, 71
 specific heat of, 71
 American Society for Testing
 Materials, sampling and
 analysis of pig iron, 224
 Ammonia, 18
 bases, 39
 containers, 36, 39
 Ampere, 143
 Analysis (analyses)
 of brass foundry sands, 287
 of iron, 14
 of iron-foundry sands, 290
 of pig iron, 224ff.
 of return iron, 227
 of sand, 271ff.
 of steel-foundry sands, 293ff.
 Annealing, 7, 24, 30, 263, 323
 effect of, on tensile strength, 24
 qualities of iron, 24
 Ash, 6, 96ff.
 Atmosphere (see also *Air*).
 composition of, 18, 86
 pressure of, 80, 239ff.
 Atom (atoms), 10, 15
 defined, 10
 Austenite, 182

B

Bars, cleats, 68, 366, 400
 Bases (basic substances), acids,
 bases, and salts, 38ff.

- Bases (basic substances), ammonia,
39
caustic potash, 39
soda, soda ash, 39
and sulphur, 204
test for, 39
used in foundry, 45
used in galvanizing metals, 38
- Bath, 400
- Bed, bed charge, 400
depth, height of, 242, 249, 251,
263, 265
lighting, 248
- Bessemer converter, furnaces, 220
source of heat in, 96, 99
- Binders (see also *Bond*), 15, 400
cores, 298ff.
in steel-facing sands, 315
mineral, 298
oil, 300
organic, 282, 294, 298
requirements in cores, 300
resin, 298, 302
water-soluble, 291, 298
- Blacking, 400
- Blast, 400
hot-blast cupola, 252
time of putting on and off, 251,
266
- Blast furnace, 214ff., 215 (Fig. 53)
air used in, 216
bosh, 214
combustion in, 216, 218
description of, 214
hearth, crucible, 214
operation of, 218ff.
- Blow holes, 30, 400
- Bod, 251, 400
- Bond (bonding materials) (see also
Binders, Sand, Cores), 26
core binders, 298ff.
dry bond, 279
green bond, 279
of core sand mixtures, Chart II,
301
strength, 272, 276ff.
measurement of, 279ff.
- Borings, 229, 230
use of, as problem, 70
- Bottom board, 282, 345, 354, 370,
400
doors in cupola, 243, 247
- Brass, 13
bond in brass sands (Chart I),
277
composition, 58
contraction of, 30
foundry sands, 287ff.
protection from strains in pour-
ing, 101
selection of sands, 285
- Breast, 400
building of, 249
freezing, 251
- Brick, fire, 235, 402
in cupola construction, 236, 247
melting data, 74 (Table III)
specific gravity, 56 (Table II)
- British thermal units (B.t.u.)
absorbed in melting of metals,
70ff.
defined, 70
per pound of element burned,
97 (Table IV)
of fuel, 97 (Table V)
- Brittleness, 24, 25
- Bull, Major R. A., "Elementary
Problems in Steel-foundry
Production," 305ff.

C

- Calcium, 9, 11, 14
- Calculation of mixtures for cupola.
4, 20, 254ff.
borings in, 230
cost of mixture, 261
effect of change on shrinkage, 24
example of calculation, 256ff.
manganese, 195, 255ff.
phosphorus, 255ff.
pig iron, 256ff.
scrap in, 227, 255ff.
silicon, 92, 185, 254ff.

- Calculation of mixtures for cupola,
 steel, 37, 256*ff.*
 sulphur, 204, 254*ff.*
- Calorimeter, 131
- Capillary action, 26
- Carbon, 6, 9*ff.*, 19
 amount in gray cast iron, 179
 and manganese, 193*ff.*
 and silicon, 187, 193
 and sulphur, 203
 combined, 14, 20
 effect on shrinkage, 35
 in pig iron, 222
 combustion of, 96*ff.*, 99
 B.t.u.'s produced, 96
 complete, incomplete, 98*ff.*
 fixed carbon, 97
 effect of carbon on iron, 179*ff.*
 melting point of iron, 76
 fluidity of iron, 76
 fixed, percentage in coal, 97
 (Table V)
 free, graphite, 14, 20, 180
 as lubricant, 65
 in high-test cast iron, 262
 effect on hardness of iron, 180
 on machinability, 188
 shrinkage, 35
 strength, 180
 heat from solution in iron, 78
 lamp black, 96
 non-metal, 16
 proportion of free and combined,
 15
 effect of, 34, 180*ff.*
 total in iron, 14
 in cupola mixture, 255
- Carbon dioxide, 15
 characteristics of, 105
 effect on animal life, 104*ff.*
 production of, 89, 98*ff.*
- Carbon monoxide, 15, 242
 as fuel, 252
 characteristics of, 106
 danger from, 89, 98, 104*ff.*
 production of, 89, 98
- Carron oil, 45
- Casting, to size, 29, 331, 358, 383
- Castings, 13
 agricultural, 355
 cleaning, 40*ff.*, 324
 defects in (see also *Shrinkage*), 4
 blow holes, 203
 cold shuts, 5
 dirty, 203, 278, 282, 313
 gas holes, 102, 230
 leakers, 37
 rough surfaces, 278, 281*ff.*,
 291, 297
 scabs, 7, 404
 shot, 7, 199
 shrinkage, 203, 230
 effect on, of sulphur in iron, 19
 expansion of, 29*ff.*
 hardness of, 4
 measurement of specific gravity,
 55
 selection of sand, 281
 size and weight of steel, 312*ff.*
 strength of, 20
- Cementite (see *Iron carbide*).
- Centigrade, scale, degrees, 50 (Fig.
 3), 51
- Chaplet, 400
- Charging door, 401
- cupola, 265*ff.*
 arrangement of materials, 230
 principle, 250
 charging zone, 245
 coke, 265*ff.*
 constituents of charge, 16, 241
 hand charging, 267
 mechanical charging, 267*ff.*
 procedure in, 249*ff.*
 size of charges, 266
 thickness of charge, 79
 electric furnace, 317*ff.*
- Cheek, 401
- Chemical attractions, 11, 18*ff.*, 23,
 182, 194
 influenced by, 18
 of bases and acids, 39
 changes, 5, 6, 14, 15, 20, 182
 defined, 5

- Chemical attractions, changes, during cooling of metals, 31
 - examples, 7
 - composition of sands, 271*ff.*
- Chemistry, 3
 - chemical symbols, 11*ff.*
 - of compounds, 15
 - defined, 11
 - chemist service, 3
 - in foundry, 3
 - most fundamental law in, 4
 - scope of, 3
- Chills (chilling), 401
 - in casting of pig iron, 222
 - in preventing shrinkage, 33
 - manganese, 194
 - of steel, 319
- Chipping-out the cupola, 247, 401
- Chromium, 14
- Clay, 4, 15
 - bentonite, 285
 - clay wash, 26, 401
 - adhesion of, 24
 - fire, 235
 - burnt, 39
 - in bond, 295
 - in sand, defined, 272*ff.*
 - plasticity, 277
- Cleaning of castings, 88
 - by acids, 40*ff.*
 - devices, 41 (Fig. 2), 42
 - in electric steel foundry, 324*ff.*
 - hydraulic, 40
- Coal (see *Fuel*).
- Coefficient of expansion of solids, 29
 - of friction, 67
- Cohesion, 23*ff.*, 25
 - defined, 23
 - effect of, 28
 - in cooling iron, 31, 32
 - in iron, affected by graphite, 34
 - in sand, 279
 - versus* adhesion, 25
- Coke, 4, 6, 14, 99
 - amount used in melting, 263*ff.*
 - blast furnace, 218
 - Coke, by-products in manufacture of, 11
 - cause of defects in castings, 205
 - composition of, 97
 - proportion of iron and coke in charge, 250
 - shipping of, 212
 - sulphur in, 204
- Cold shots, 401
- Combustion, 7, 21, 95*ff.*
 - defined, 95
 - in blast furnace, 216, 218
 - of bond, 101
 - products of, 15, 104*ff.*
 - spontaneous, 87, 100*ff.*
- Compounds, defined, 14
 - effect of, in cupola, 21
 - examples of, 17
- Compressive strength, test of, 62
- Conservation (law of conservation), of energy, 6
 - of matter, 6
- Containers, ammonia, 36, 39
- Contraction, 28*ff.*, 401
 - amount, in cast iron, 29
 - distinguished from shrinkage, 28
 - provisions for, in casting, 30
- Converter, Bessemer, furnaces, 220
- Cooling of iron, effect of slow and quick, 34
- Cope (see in Part XII, *Molding machines*)
 - board, 345
 - defined, 401
 - free, 58
- Copper, 10
 - latent heat of fusion, 71
 - melting of, 71
 - specific heat of, 71
- Core (cores), 297*ff.*, 401
 - baked, 400
 - blackening of, 23
 - blending of, 300*ff.*
 - bonding of, 101
 - box, 401
 - compound, 401
 - dry sand, 25

- Core, green, 26
 irons, 401
 made by machinery, 394ff.
 making and baking, 302ff.
 prints, 401
 sands for, 297ff.
 wash, 401
 yielding, 30
- Cupola, 7
 air passing through, 18, 237
 control of amount of air, 238ff.
 description of, 235ff.
 dump, 402
 fuel, 97
 hot-blast, 99
 lining, 235
 melting rate, 251
 melting zone, 92, 94, 99, 265
 mixture, 13
 operation, 4, 247ff.
 affected by humidity, 80
 blast, 251
 charging, 249ff.
 effect of weather, 240
 efficiency, 100
 fuel, 99, 248
 lighting up, 248
 preparations for heat, 247
 tapping, 251
 use of gravity in, 128
 size of, 235
 zones, 243
- Cutting theory to fit facts, 21
- D
- Daubing (daubing up), 247, 401
- Density, 30, 53ff.
 of jolted sand, 69
- Deoxidizers (see *Reduction*).
- Desulphurization, 19, 195
 of cast iron, 204
- Draft in cupola, 237ff., 248
 forced, 21
 of pattern, 402
- Drag (see in Part XII, *Molding machines*).
 defined, 402
- Draw plate, 402
- Drawing pattern, 372, 402
- Drop (drop-out), 228, 402
- Dump, cupola, 402
- E
- Efficiency of machines, 68
- Elasticity, 61ff.
 elastic limit, 61ff.
- Electric furnace, basic lined, 204
 charging of, 317ff.
 electrodes in, 317
 in steel casting manufacture, 235, 307ff.
 principle of, 144
 reasons for rapid growth of, 307
 types of, 308ff.
 steel castings, cleaning equipment, 324ff.
 equipment in manufacture of, 317ff.
 heat treatment and equipment for, 323
 laboratory service in manufacture of, 325ff. (Fig. 74)
 manufacture of, 307ff.
 uses of, 311 (see also *Electric furnace, in steel-casting manufacture*).
 steel foundry, 307ff.
- Electricity, 140ff.
 alternating current (a.c.), 144
 direct-current (d.c.), 144
 electric current, 6
 electrolysis, 6, 88
- "Elementary Problems in steel-foundry Production," by Major R. A. Bull., 305ff.
- Elements, 9ff., 11
 action in cupola charge, 21
 combinations of, 13ff.
 definition, 9, 10
 effects on cast iron, 179ff.
- Emerson, Harrington, "Efficient Management," 336

- Energy, 115, 118*ff.*
 conservation of, 119
 forms of, 118
 kinetic, 119
 potential, 119, 129
 sources of, 85
 Eutectic, 180, 402
 Expansion, 28*ff.*
 coefficient of, solids, 29
 linear, 28
 of castings, 29*ff.*
 of water before freezing, 30
 table of linear expansion,
 common metals, 29 (Table I)
- F
- Facing (facings), 282, 402
 foundry, 12
 green sand molding, 294
 of large cores, 303
 mulling of, 291
 steel facings sands, 315, 320*ff.*
 Fahrenheit, scale, degree, 50 (Fig. 3), 51
 Federal Specifications Board,
 grades of pig iron, 185, 223
 Feeding castings (feeders), 31, 32, 402
 head, 402
 Ferrite, 182
 Ferromanganese, 12, 182, 192, 193, 263
 Ferrosilicon, 186, 263
 added to ladle, 16
 Fin, 402
 Firestone, Harvey S., 332*ff.*
 Flame, 95
 Flasks, 282, 402
 snap, 345*ff.*
 solid, 355
 Fluidity, 99
 carbon, 76
 of iron affected by iron oxide, 93
 of molten metals, 75*ff.*
 phosphorus, 77, 186, 198*ff.*
 silicon, 76
- Fluids, defined, 5
 hydraulic press, 170*ff.*
 mechanics of, 167*ff.*
 transfer of heat, 136
 transmission of pressure by, 167*ff.*
 Fluxes, 7, 272, 402
 basic, 44*ff.*
 in blast furnace, 218
 in cupola charge, 249
 Follow board, 402
 Foot-pounds, 115*ff.*, 119*ff.*, 123
 Force (forces), 111*ff.*
 defined, 111
 gravity, 128*ff.*
 hydraulic press, 172
 inclined plane, wedge, screw, 162*ff.*
 measurement of, 111
 pulleys, 154*ff.*
 resultant of, 113
 water cylinder, 167*ff.*
 Ford, Henry, 332*ff.*, 382
 Founding, 402
 Foundry, brass, 12
 employment multiplied through
 machine production, 333
 ferrous, 12
 industry, development of, 3, 226
 progress in, 238*ff.*, 382, 385
 practices affecting life of metal, 78*ff.*
 sandless, 382
 ventilation in, 106
 Friction, 64*ff.*, 115, 163
 and efficiency, 67*ff.*
 coefficient of, 67
 laws of sliding, 64
 two kinds of, 64
 Fuel (fuels), 14
 analysis, 96
 blast-furnace, 218
 combustion of, 96*ff.*
 composition and heating value
 of coal, table, 97 (Table V)
 heat units in, 131
 powdered coal, 252

Fuel, spontaneous combustion of, 100ff.
 sulphur in, 202
 Fusion, temperature of sand, 276ff.

G

Gaggers, 24, 26, 58, 68, 402
 Gas, 18
 defined, 5
 in molds, 281ff.
 in solution, 16
 in "wild" metal, 281
 steam, 175
 Gates, 402
 location of, 32, 36
 pattern of, 367
 Gears, 158ff.
 Generator, 144
 principle of electric, 142 (Fig. 18)
 Grain of gray-iron castings, 22
 influenced by contraction and shrinkage, 28ff.
 by manganese, 35, 195
 by silicon, 35
 Graphite (see *Carbon, free*).
 Gravity, 25
 as force, 128ff.
 specific, 53ff., 219
 table of, 56 (Table II)
 Griffin hot-blast cupola, 100
 Grubb, A. A., "Foundry Sands," 269ff.

H

Hardness, 24, 25
 Brinell, scleroscope measures of, 25
 Heat, as force, 130ff.
 as tonnage of metal in cupola, 247, 403
 British thermal unit, 132
 calorie, 131
 conduction, 135
 conductivity of metals, 72
 convection, 136

Heat, effect of, on metals, 70
 effect on sand, 276ff.
 of solution in setting of iron, 77
 latent heat, 77, 133ff.
 of metals, 71
 measure of, 130ff.
 melting data, table, 74 (Table III)
 of evaporation, 134
 table, 135 (Table VIII)
 of fusion of metals, 72
 table, 134 (Table VII)
 radiation, 135
 sensible, 77
 sources of, 95
 specific, 71ff., 132ff., (Table VI)
 stages of absorption in melting, 70
 transmission of, 135ff.
 treating equipment in electric steel foundry, 323
 value of elements, table, 97 (Table IV)
 Hematite, chemical symbol of, 17
 sources, 210
 High-test cast iron, 250, 262ff.
 Horsepower, 68
 defined, 123
 kilowatt equivalent, 143
 Humidity, 80ff.
 Hydraulic press, 170ff.
 Hydrogen, 6, 10, 15, 95
 oxidation of, 88

I

Inertia, 59ff.
 uses in foundry, 60
 Iron, 4, 9, 13
 analysis, 14
 and carbon, 179ff.
 and manganese, 192ff.
 and phosphorus, 44ff., 197ff.
 and silicon, 185ff.
 and sulphur, 20, 202ff.
 basic in character, 45
 carbide, cementite, 14, 182, 400

Iron, carbon heat from solution in, 78

total in, 14

combustion of, 95

density of cast, 53

dull, 402

effects of elements on cast iron,
179ff.

elasticity of cast, 62

foundry sands, 290ff.

fracture of, 15

gray, defined, 402

standard specifications for
castings, 62

hardening of, 14

hardness of, 20

in sand, 271

malleable, 235, 403

melting points of cast, 76ff.

molecule of, 11

occurrence, 209ff.

ores, (see also *Hematite*, *Magnetite*, *Siderite*), 209ff.

mining of, 210

smelting in blast furnace, 216,
218ff.

transportation of, 212ff.

oxides, rust, 14, 22, 87

hematite, 14, 86

magnetite, 14

oxidized, 19, 36, 91, 92, 93

proportion of metal in charge,
250ff.

pure, 13

hardness, 179

melting point, 75

return iron, 227

rust, 13, 85

strength of, 13

symbol of, 11

white, 34

wrought, 222

K

Kimber, Harry, 382

Kindling conditions, 96
temperature, 96

Kinetic energy, 119

L

Ladle, bull, 400

drying of, linings, 81

Lavosier, 6

Lead, 10

black, 400

oxide, 85

Levers, lever systems, 129, 149ff.

classes of, 149ff.

fulcrum, 149

Life of molten metals, 75ff.

Light, 137ff.

Lime, 45

absorbing sulphur, 204

in sand, 271

limestone, 14

in blast furnace, 218

in charging cupola, 249ff.

quick, 15

slaked, 15

slaking of, 7

Liquids, defined, 5

in solutions, 16

in suspensions, 16

Litharge, 347

Litmus, 39

Loam, 403

molds, 292

Long-life, "permanent" molds,
380ff.

Lubricant, 65

graphite as, 65

Luminosity, 96

M

Machinability, 403

Magnesium (magnesia), 45, 86
in sands, 272

Magnetite, chemical symbol of, 17
sources of, 210

Magnets (magnetism), 140ff.

Malleability, 24

defined, 24

Manganese, 11

added to ladle, 20

- Manganese, and carbon, 193*ff.*
and oxygen, 192, 194
and silicon, 193
and sulphur, 20, 194, 202, 203
calculation of mixtures, 255*ff.*
chill, 194
combustion of, 99
effect on cast iron, 19, 181, 192*ff.*
on amount of carbon in iron,
34, 181
on grain of castings, 195
on hardness, 22, 194
on shrinkage and grain of iron,
34
loss in cupola, 91
occurrence, 192
sacrifice of, to carbon, 194
variations in purchase of pig
iron, 223
- Match, hard oil sand, 342, 347*ff.*
boards, 343
plates, 343*ff.*, 403
- Measurements, 49*ff.*
Centigrade and Fahrenheit
scales, 50 (Fig. 3), 51
- Mechanical advantage (M.A.),
155*ff.*, 171
production in foundry industry,
331*ff.*
and employment, 333
- Mechanics of fluids, 167*ff.*
- Melting, cost, factors in, 72
data table, 75 (Table III)
hot iron desired, 266
loss, 91, 230, 403
manganese, 92, 192
silicon, 92, 186
other sources of, 92
points of metals and alloys,
70*ff.*, 75
high-test iron, 263
rate, 403
ratio, 242, 263, 403
temperature as to size of cast-
ings, 99
of iron affected by carbon, 76
by phosphorus, 198
- Melting, temperature of iron
affected by silicon, 188
zone, 244, 249, 263, 403
- Mending up, 403
- Mesaba district, 211
- Metals, 9
fluidity, 4
form basic compounds, 44
latent heat of, 71
melting data, 74 (Table III)
mixing, 4
molten iron avoids hard spots in
sand, 68
pouring, patterns as to design,
32
transmutation, 9
- Metric system, 49, 51
- Mixtures of substances, 15*ff.*
- Moisture, control of sand, 284
requirements of sands, 282
resistance of cores, 297
rusting of iron, 88
- Moldenke, Richard, high-test cast
iron, 262
long-life molds, 380*ff.*
procedure in charging cupola,
249*ff.*
- Mold board, 403
- Molding cost affected by molding
machines, 331
- Molding machines, and foundry
equipment, 129, 170, 173,
331*ff.*, 403
air compressors, 350
bottom boards, 370
cleaning of machines, 348
conveyers, 359
core-blowing, 394*ff.*
knockout, 398
cranes, 368
drawing (pattern), 339, 355,
359, 365, 374*ff.*
flask, 366*ff.*, 377
roll-off, 359
gate, 367
general, combination or multi-
ple-type, 378, 385

- Molding machines, hard-sand match, 347*ff.*
 Holley, 383*ff.*
 in development of foundry industry, 331
 jar- and jolt-ramming, 68, 302, 320, 352, 356*ff.*, 369, 377*ff.*, 403
 match plate, 344*ff.*, (Fig. 81), 403
 pattern equipment, 378*ff.*
 pouring jacket, 345
 ramming, 339, 365, 377*ff.*
 rigging, 366
 roll-over, 339, 361, 372*ff.*, 404
 sand blowers, 302
 blowing, 393*ff.*
 mixer, 320
 sandslinger, 385*ff.*
 snap flasks, 345*ff.*
 split pattern, 357
 sprue cutter, 347
 patterns, 347, 367
 squeezers, 302, 320, 338*ff.*, 350*ff.*, 405
 types of power, 350*ff.*
 stripping plate, 356*ff.*, 363*ff.*, 368*ff.*, 405
 vibrator, 342, 350
- Molds, 403
 damp, 188
 defects in, blows, 284, 291
 in cracked, 278
 in drops, 278
 in misruns, 284
 effect on rate of cooling, 380
 for casting pigs, 220
 loam, 403
 long life, "permanent," 380*ff.*
 major and minor operations in making of, 372
 sizes of, squeezed by hand, 346
- Molecules, 15
 attractions between, 23, 25
 defined, 10
 molecular arrangement modified by, 24
- Momentum, physical, 125
 in production methods, 334
- Motion, 125*ff.*
 kinds of, 126
- N
- Nitric acid, 18, 40
 Nitrogen, 21
 compounds of, 18
 in air, 18
 nitroglycerin, 18
 Nowel, 403
- O
- Ohm, 143
 Oils, drying, 87
 non-drying, 298
 Oxidation (see also *each metal*), 85*ff.*, 95
 in cupola, 250
 of metals, 91*ff.*
 oxidizing flame, 70
 slow, 87
 Oxy-acetylene, 6, 21
 Oxygen, 6, 9, 10, 13, 19, 22, 70, 85*ff.*
 amount used in cupola, 241
 an active element, 11, 85
 as element, 7, 14
 control of supply of, in cupola, 93
 effect of, on setting point of iron, 77
 life of iron, 78
 in solution in rubber, 16
- P
- Parting, 347, 403
 Pascal's law, 167
 Patterns, 30
 design as to pouring metals, 32
 effect of thickness on ramming, 63
 equipment in electric steel foundries, 319*ff.*
 used on squeezers, 341

- Patterns, gated, 342
 placing of, 32
 split, 343, 354, 405
 pattern machine, 357
 sprue, 347
 Pearlite, 180, 182
 Peeling, 403
 Peen, 343, 404
 Permanent set, 61ff.
 Permeability of cores, 297
 Chart II, 301
 of sands, 281ff., 284ff.
 Phosphorus, 9, 78
 attraction for iron, 20
 calculation of, in mixtures, 255ff.
 effect on cast iron, 20, 197ff.
 on fluidity, 186, 198ff.
 on life, 78
 on melting point, 77, 198
 on strength, 198
 forms of, 197
 from flux, 197
 not oxidized in cupola, 91, 197
 occurrence, 197
 variations allowed in purchase
 of pig iron, 223
 Physical changes, 5, 182
 defined, 5
 states of matter, 4
 of iron, 5
 of substances in solution, 15
 Pickling of iron castings, 40ff.
 Pig bed, 404
 iron, 3
 as semi-raw material, 214
 analysis, 224ff.
 chills, 222
 classification, 222ff.
 comparison of sand and
 machine-cast, 222
 grades of, 185ff.
 in calculating mixtures, 256ff.
 in charging cupola, 250
 machine-cast, 219ff., 222
 manganese in, 182
 phosphorus in, 197
 Pig iron, production in blast
 furnace, 218ff.
 purchase of, 185, 198, 202,
 222ff.
 sampling and analysis of, 224
 sand-cast, 219, 222
 silicon in, 186
 sources of, 209ff.
 sows, 220
 sulphur in, 202
 tests of, 186
 use of scrap, 226
 variations allowed in pur-
 chase, 223
 Plane, inclined, 162ff.
 Plumbago, 45
 Pneumatic machinery, 170ff.
 tools and equipment, 173ff.
 Points in statement of constitu-
 ents of iron, 223
 Porosity (see also *Grain of cast-
 ings*), 22, 28
 Portland cement, 219
 Positive blower, 238ff.
 Pouring, 404
 basin, 404
 metals, patterns, 32
 of steel, 318ff.
 time, 79
 Powdered coal, 252
 Power, 123ff.
 gears, 158ff.
 Pressure, atmospheric, 80
 hydraulic, 170ff.
 of air in cupola, 238ff.
 transmitted by fluids, 167ff.
 Prop, 251, 404
 Pulleys, 154ff.
 Pumping of molten metals, 404
 Pyrometer, 131 (Fig. 11), 138

R

- Radioactivity, 10
 Ramming (rammer), 57, 282, 366,
 372, 404
 by hand or machine, 338
 energy of, 120

- Rapping plate, 404
 Reduction, 93, 194
 deoxidizing agents in cupola, 19, 186, 194
 in blast furnace, 218
 Refractories (refractory materials), 38, 73, 404
 acid, 214
 basic acid, neutral, 45
 cores, 297
 fire-brick, 214
 in steel foundry, 294
 refractoriness in sands, 276
 sand, 271*ff.*
 steel-molding sand, 314
 Research, 13
 in cleaning castings, 41
 subjects of study, 5
 Riddle, 404
 Riser (risers), 31, 36, 344, 404
 location of, in preventing shrinkage, 32
 Runner, 404
 Run-out, 404
 Rust, iron, 13, 85
 from sulphuric acid, 42, 43
- S
- Salt (salts), 11
 acids, bases and salts, 38*ff.*
 chemical symbol of, 39
 formation of, 38
 Sampling and analysis of pig iron, 224
 Sand (sands) (see also *Bond*, *Cores*), 4, 5, 15, 16, 269*ff.*
 additions to, 285*ff.*
 adhesion of, 24
 alumina, 271
 an acid in cupola, 249*ff.*
 analysis, 271*ff.*
 blending of core sands, 300*ff.*
 bonding of, 101, 272
 bottom, 248, 400
 brass, 287*ff.*
 burnt, 400
 Sand, chemical composition, 271*ff.*
 clay, 272*ff.*
 composition of, 291
 conditioning, 288
 control, 284*ff.*
 core sands, 297*ff.*, 300, 401
 cutter, cutting, 291, 340, 354
 cutting over, 401
 effect of capillary action on, 26
 fire, 402
 grading, 274*ff.*
 grain fineness, 272*ff.*, 281
 shape, 274
 green, 282, 402
 heap, 276, 282, 285, 403
 in cleaning castings, 40
 iron, 290*ff.*
 measurement of specific gravity, 55
 mixers, 278 (Fig. 66)
 mixing, 299*ff.*
 moisture, 278
 molding, 271*ff.*, 403
 parting, 403
 permeability, 281*ff.*, 284*ff.*
 plasticity, 276
 problems in electric steel manufacturing, 313*ff.*
 selection of, for size of castings, 281
 slinger, 285
 steel, 293*ff.*, 314*ff.*, 320*ff.*
 temper (tempering of), 4, 248, 276, 281*ff.*, 294, 405
 testing size, 272
 texture, 272
 weak, 278, 405
 Saving in foundry, 331*ff.*
 of labor, 331
 power, 331
 Scavengers in cupola, 19, 93
 Scrap, 7, 226*ff.*, 404
 classification of, 228*ff.*
 domestic, 227*ff.*
 in calculating mixture, 255*ff.*
 in high-test cast iron, 263

- Scrap, effect on shrinkage, 36
 on melting point, 75
 foreign, 227, 228*ff.*
 machinery, 228
 source of sulphur, 203
 use of waste as, 70
- Screw, in application of force, 162*ff.*
- Sea-coal, 272, 404
- Segar cones, 276
- Setting of molten iron, process, 31
 rule for time of, 36
- Shot, casting defect, 199
- Shrinkage, 28*ff.*, 195, 230, 404
 distinguished from contraction,
 28, 31
 head, 402
 increased by oxidized iron, 93
 in steel foundry, 312
 overcoming difficulty of, 32*ff.*, 36
- Shrink-holes, 33, 404
- Silica (see also *Sands*).
 acid in character, 39, 44
 distinguished from silicon, 185
 sands, 271
- Silicon, 9, 11, 19
 and carbon, 187, 193
 and manganese, 193
 and other elements in iron, 188
 and oxygen, 19, 78, 185, 186
 and sulphur, 203
 calculations of, in mixtures, 185,
 254*ff.*
 combustion of, 99
 effect on cast iron, 185*ff.*
 on amount of combined car-
 bon in, 34, 181, 187
 on fluidity, 76
 on hardness, 20, 187*ff.*
 on life, 78
 on melting point, 76
 on shrinkage and grain, 34, 35,
 36
 loss in cupola, 91, 92, 186
 occurrence, 185
 review of effect on iron, 190
 variation in purchase of pig
 iron, 223
- Silicospiegel, 192
- Skill in electric steel foundry, 326
 needed in foundries, 331, 334,
 385
- Skim-gate, 404
- Skin-drying, 404
- Slag, 404
 as suspension, 16
 corrosive effect of, 38
 height in cupola, 215
 in steel furnace, 39
 making, 319
 spout, 243
- Slick, (slicker, smoother), 404
- Slosson, E. E., 21
- Soldiers, 26, 405
- Solids, 4
 in solution, 16
 in suspensions, 16
- Solubility, affected by, 16
- Solutions, 14
 defined, 15
 in cupola, 179
- Solvent, 16
- Solute, 16
- Sorbite, 182
- Specific heat of aluminum, 71
 of copper, 71
- Specialization in production, 334
- Spout, 405
- Sprues, 405
- Standards for melting loss, 91
 for product, 4
 in pig iron, 222
 of living, 333
 specifications for gray iron cast-
 ings, 63
- Steam, pressure, 175
 volume compared to water, 5,
 281
- Steel, 179
 as alloy, 16
 boiling of Bessemer, 99
 composition of, 179
 foundry sands, 293*ff.*
 in charging cupola, 249*ff.*
 manganese steel scrap, 192

- Steel, manufacture in blast furnace, 220
 rustless, 13
 scrap, 230
 in calculating mixtures, 256ff.
 in high-test cast iron, 263ff.
 making electric-steel, 309
 selections of sands, 285
 Stopping off, 405
 Stopping up, 405
 Strain, defined, 62
 Stress, 30
 defined, 62
 ultimate, 62
 Stripping machines, 356ff., 363ff.
 plate, 405
 reasons for success of, 363ff.
 Substances, as chemical term, 4
 number of, 11
 structure of, 9, 13ff.
 Sulphur, 4, 6, 11, 19
 and carbon, 203
 and manganese, 195, 202, 203
 and silicon, 202
 calculation of mixtures, 254ff.
 "dead line" for amount in castings, 203
 dioxide, effect on lungs, 106ff.
 effect on cast iron, 202ff.
 on amount of carbon in, 181
 on shrinkage, 35
 on time of setting, 203
 hardening effect of, 20
 increase in cupola, 91, 203ff.
 occurrence, 202
 Superheating in high-test iron, 250, 262ff., 266
 Suspensions, 14
 colloidal, 16
 defined, 16

T

- Tackles, 154ff.
 Tap hole, 251, 405
 Taylor, Frederick W., "Economic Production through Labor-saving Equipment," 335

- Temper of iron, 24
 Temperatures, blast furnace, 218
 difficulties related to high temperature of metal, 312
 effect of, on chemical changes, 20
 on substances, of change in, 30
 on weight of air, 239
 in electric furnace, 307
 melting (see *Melting temperature*).
 of iron, effect on shrinkage, 32
 effect of differences in, 32
 pouring, 263
 of brass, 287
 of iron, 290
 of steel, 294
 compared to iron, 314
 regulation of temperature of mold, 383
 Tensile strength, 24
 defined, 24
 effect of annealing on, 24
 of iron alloys, 182
 test of, 62
 Tension, surface, 25
 Test, for acid, 39
 sintering, 276
 testing, bond strength in sand, 279ff.
 green bond of sand, 284ff.
 permeability of sand, 282, 284ff.
 Tests, of pig iron, 186
 Titanium, 13
 "Tricks of the trade," explained scientifically, 21
 Tucking, 348, 356, 366, 405
 Tuyeres, 92, 243, 405
 shape and size, 237
 above slag, 219
 use of, 214

U

- United States Bureau of Standards, 91

V

- Vanadium, 19
- Velocity, 125
 - of falling bodies, 120
- Vent (venting), 57, 68, 282, 405
 - quality of sands, 281ff.
- Vibrator, 26, 342, 347, 350, 405
- Volatilization, 96
 - of fuels, 97
 - of metals, 70, 101
- Voltage, 142

W

- Water, as compound, 14, 75
 - combined in sand, 271, 276
 - cylinder, 167ff., 168 (Fig. 48)
 - decomposition of, 6
 - elements in, 10

- Water, expansion and contraction
 - in cooling, 30
 - hydraulic press, 170ff.
 - proofing, 24
 - solution in, 77
 - specific heat of, 71
 - symbol for, 15
 - unit of specific gravity, 54, 55
- Watt (kilowatt), 143ff.
 - and horsepower, 143
- Wedge, in application of force, 162ff.
- Weight (weights), 53ff.
 - of air in the cupola, 239
 - table of weights, 56 (Table II)
- Work, 115ff., 118, 123
 - and pulleys, 154ff.
 - done by steam, 175ff.
 - hydraulic press, 172
 - inclined plane, wedge, and screw, 162ff.

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